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Flight Crew Interface Aspects of Forward-Looking Airborne Windshear Detection Systems

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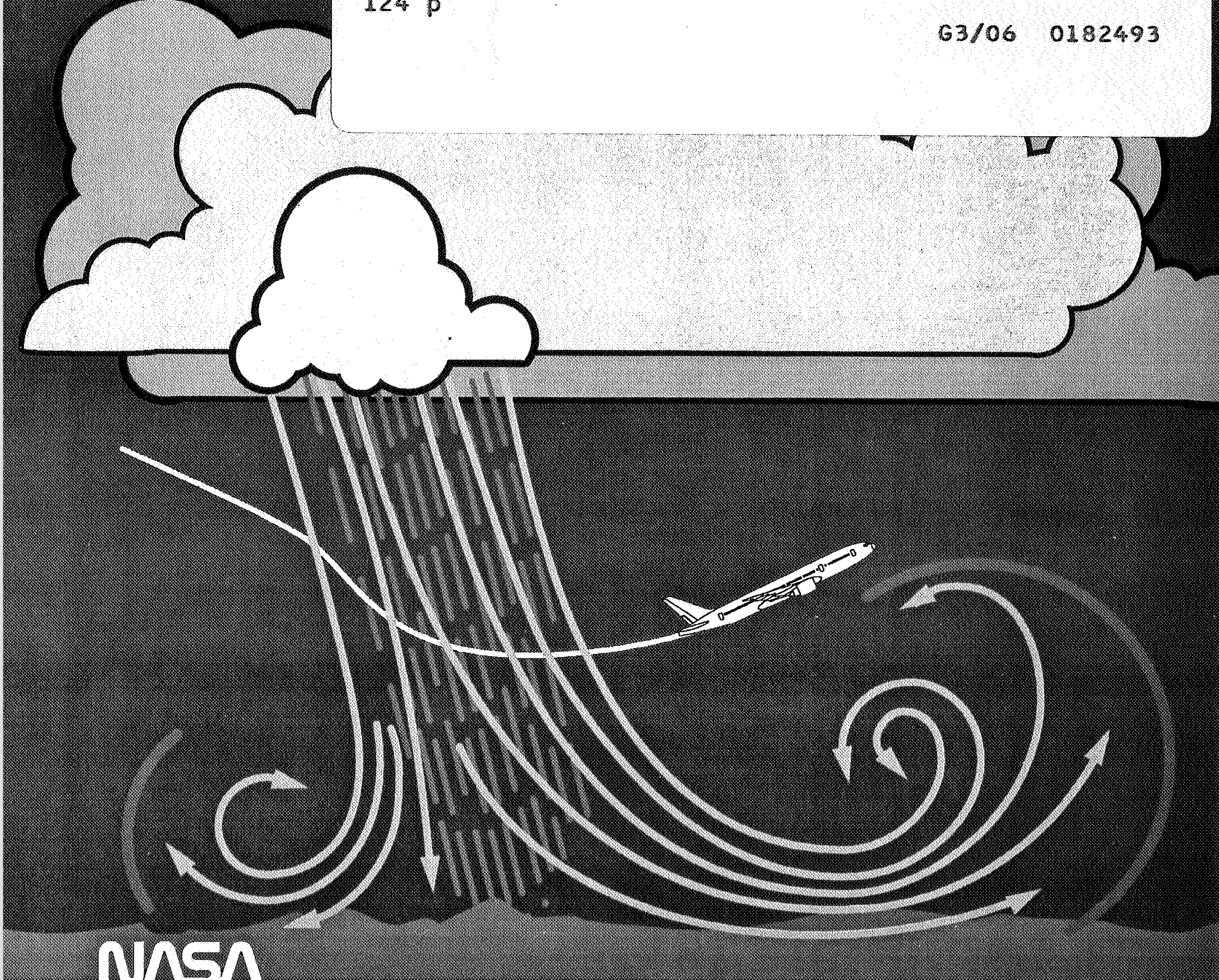

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July 1993
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FLIGHT CREW INTERFACE ASPECTS

OF

FORWARD-LOOKING AIRBORNE WINDSHEAR DETECTION SYSTEMS

NASA Contract NAS1-18027
Task 9A

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LIST OF TERMS AND ABBREVIATIONS

AGL	Above Ground Level
ARINC	Aeronautical Radio Incorporated
BCAG	Boeing Commercial Airplane Group
DDS	Display Development System
EADI	Electronic Altitude Directional Indicator
EFIS	Electronic Flight Instrument System
EICAS	Engine Indication & Crew Alerting System
FAA	Federal Aviation Administration
GPWS	Ground Proximity Warning System
HUD	Head-Up Display
LaRC	Langley Research Center
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
PC	Personal Computer
PFD	Primary Flight Display
QRH	Quick Reference Handbook
SAE	Society of Automotive Engineers, Inc.
TCAS	Traffic Alert & Collision Avoidance System
WS	Windshear

1.0 INTRODUCTION

Much progress has been made in understanding and coping with the windshear phenomenon since the FAA initiated a program in 1967 to reduce the hazard of low-level windshear. Highlighting this program is the requirement to provide timely and accurate information to the flight crew so they can avoid or deal with hazardous windshear. As development of improved windshear sensors progresses and knowledge of the windshear phenomenon expands, the requirement for proper crew interfacing of this new technology/information becomes necessary. The recent development of new airborne and ground sensors, along with improved computing and display capabilities, gives the quest for proper integration and crew interface an increased level of complexity and concern.

In 1986, the FAA initiated it's Integrated Windshear Program Plan. The objective of the integrated program was to: "...address the windshear problem by facilitating the transfer of technology to the operational arena, by means of education and training programs, and by the development of surface and airborne sensing technology, as well as airborne warning and flight guidance systems..."(Ref. 1).

Five major areas of effort were addressed in the Integrated Windshear Program Plan: 1) education, training and operating procedures; 2) ground sensors for the detection of low-level windshear; 3) airborne windshear detection and avoidance; 4) terminal information systems; and 5) low level hazard characterization. A portion of the airborne area addresses on-board alerting and flight guidance systems.

The airborne part of the program plan was implemented through a joint effort between NASA and the FAA. The reason for this joint effort was to bring together all the expertise needed to define the requirements and develop a system's approach to detecting and avoiding windshear. The elements of this program that establish the base requirements for an airborne windshear detection system include hazard characterization, sensor technology, and flight management.

The Flight Deck Research(FDR) organization of Boeing Commercial Airplane Group(BCAG) was tasked to work on the flight management portion of this program. This report documents the work completed by Flight Deck Research in the first phase of this task to investigate crew interface issues with look-ahead airborne windshear detection systems. The study reported herein was one of two conducted under Tasks 9 and 9A of NASA contract NAS1-18027, and complements work performed by the BCAG Guidance & Control Group(Ref. 2). This report covers work completed in the 1988-1990 time frame. Publication was delayed due to contractor budget miscalculation.

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2.0 TASK DESCRIPTION & APPROACH

One of the major areas addressed by the FAA Integrated Windshear Program plan is that of airborne warning and flight guidance systems, and a research plan to address this area was implemented through a joint effort between the FAA and NASA.

Boeing was tasked to assist with the definition of requirements for two elements of an advanced airborne windshear detection system: hazard characterization and flight management. Hazard characterization studies and evaluation of predictive sensor concepts were conducted by Boeing to meet a portion of the **task** requirements for this NASA contract, and are documented in Volume I of this report. The "Flight **Crew** Interface" task element documented in this volume addresses the flight management portion of the airborne sensor program, including crew/system requirements, displays, and crew procedures.

Integrated windshear detection systems will incorporate look-ahead windshear detection **as** well as present-day reactive windshear detection. This task was directed toward defining the flight crew interface for such an integrated windshear system.

2.1 Task Objectives

The overall goal of this research was to provide analyses and to gather data which would help define the crew interface for an integrated windshear system. The desired end product of research in the crew interface area is to provide industry with various crew interface requirements, prototype evaluations, and display design guidelines for an integrated airborne windshear system (see Figure 2.1-1).

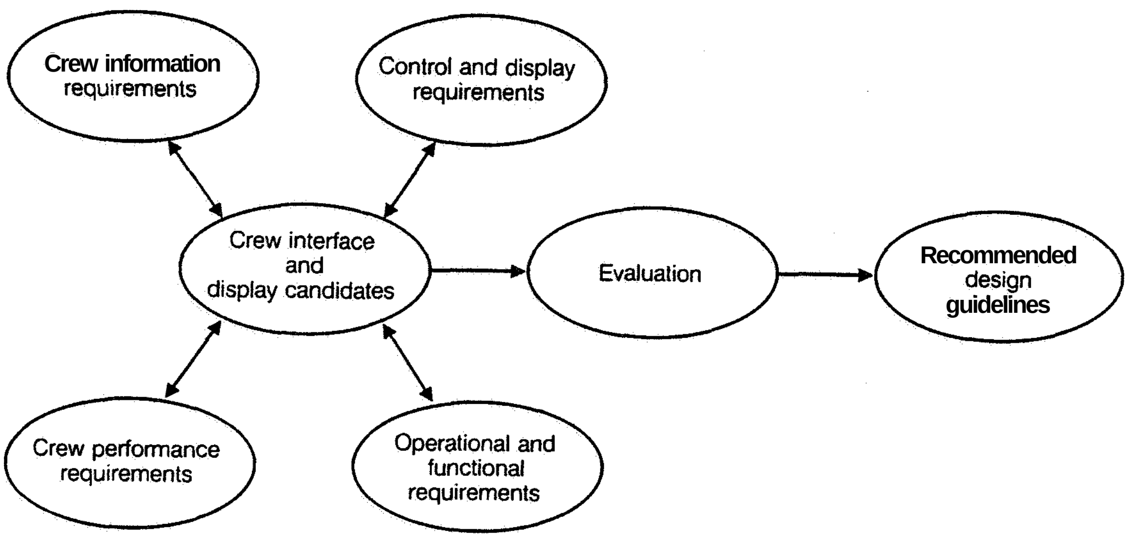

Figure 2.1-1 Crew Interface With Windshear Systems: Program Approach

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Specific task areas that needed to be worked in reaching this program goal include:

1. Establish information requirements for the flight crew in avoiding or dealing with hazardous windshear;

2. Develop candidate display formats of how that information should be presented to the flight crew;

3. Develop system objectives and guidelines for usage of advanced windshear systems, incorporating look-ahead technology and reactive system improvements, so these systems can be operationally and functionally integrated into the flight deck;

4. Develop procedures and criteria needed to demonstrate crew performance using advanced windshear systems; and

5. Evaluate candidate crew interface concepts for coping with hazardous windshear.

The Boeing effort was directed at initial research in these areas to begin to lay the groundwork for definitive resolution of crew-interface issues.

2.2 Critical Crew-Interface Issues

2.2.1 Initial Issue Identification

The look-ahead portion of advanced windshear detection raises many crew-interface issues that should be resolved prior to implementation of these detection systems. Therefore, the important issues concerning the crew interface must be known and considered during development, and the information relating to these issues should be gathered together, added to, and made readily available to all those working on advanced windshear detection systems.

Interviews with subject-area experts were used to identify an initial set of critical crew-interface issues. Boeing Flight Deck Research conducted numerous on-site interviews and telephone interviews with technologists, manufacturers, and airline companies to develop a preliminary list of critical issues that should be addressed in crew-interface investigations. Many of the issues mentioned overlapped slightly when considering their crew interface aspects, and some categorization was attempted in order to consolidate the list into relatively distinct issues.

The issues list developed was also constrained by certain limitations of this study. These included the restrictions that the issues be look-ahead-windshear-detection orientated, that they not involve mandatory FAA regulatory changes, and not be sensor specific. In addition, reactive devices were considered to be incorporated as non-throw-away technology and integral to any total windshear detection and avoidance system. Lastly,

the issues list involved the man-machine interface of airborne windshear systems only, and therefore limited the involvement of ground-based windshear systems to their on-board applications.

2.2.2 Issues Survey

The preliminary set of crew-interface issues was put in survey form and distributed to over **100** subject-area experts for comments and for a determination of the implementation impact of each issue. The estimated level **of** impact could then be used to prioritize the issues as a guide to research activities. The issues in the survey were categorized into three general areas: a) displays, b) controls, and c) alerting and crew procedures. The survey was introduced as part of a program to determine the focus and priority of research efforts involving advanced windshear detection. These issues are related to determining how much data and information the crew needs, and the development of integrated presentation concepts which consider pilot workload as an important consideration. The resolution of these issues should contribute significantly to the development and implementation of windshear detection equipment that can be used effectively and reliably by flight crews.

The survey was distributed at the SAE **S-7** meeting held **30** September **1987** in Williamsburg, Virginia. Additional copies were distributed at the First Combined Manufacturers' and Technologists' Conference held in Hampton, Virginia (Ref **3).** The survey was also reproduced and further distributed by several of the respondents in order to increase the coverage of the survey.

The objectives of this issue survey were to: **1)** identify and document crew information issues associated with advanced windshear detection systems; **2)** provide requirements for research activities to address the issues raised; and **3)** sample opinions and provide a sampling document for identifying issues of human engineering concern dealing with windshear detection. The respondents to the survey were asked to make comments on the issues and to categorize the issues in regard to implementation impact. The definitions of the "implementation impact" categories used were:

Critical:

* Issue resolution is required prior to industry-wide implementation. An issue, if left unresolved:

  1) Critically limits the operational capabilities of the system;
  2) Critically affects pilot confidence in the system; or
  3) Critically degrades flight safety in certain windshear situations.

Serious;

* Should be resolved prior to industry-wide implementation. An issue, if left unresolved:

1) Limits the operational capability of the system;
2) Affects pilot confidence in the system; or
3) Degrades flight safety in certain windshear situations.

Desirable;

* A resolution of an issue could be expected to improve the physical and/or operational man-machine interface. An issue, if left unresolved:

1) Could limit the operational capability of the system;
2) Could affect pilot confidence in the system; or
3) Could degrade flight safety in certain windshear situations.

A copy of the distributed survey is located in Appendix **I.**

2.3 Alert Warning Time & Avoidance Procedure Simulation

2.3.1 Wind Modeling and Objective

Numerous windshear models were available that adequately depict the windshear phenomenon. Boeing Flight Deck Research, in conjunction with NASA Langley, decided that, for this study, a windshear simulation segment based upon the NASA windshear model developed by Dr. Fred Proctor would be appropriate(Ref. **4).** The study used a portion of this model that replicated a high resolution, axisymmetric simulation of the DFW microburst (Ref. 5). The time frame used was **11.5** minutes (corresponding to near peak intensity) and was a wet microburst. The microburst windfield was approximately 4000 meters in diameter and extended about 750 meters vertically. This would be considered a large microburst. The core of the microburst was located 500 meters short of the runway on the extended centerline. This location was chosen because test subjects previously had accepted and attempted to land with this microburst located even closer to the runway. Locating the microburst farther out on the localizer course often resulted in go-arounds which entirely missed windfield(flew above it). As a result of the pilot initiating the go-around at a highter altitude, they were not experiencing any effects of a sink rate. In all cases at 500 meters short of the threshold, the pilots considered the go-around choice to be the best one.

One purpose in using the NASA model **was** that this very complex three-dimensional windshear model was being used by many other technologists developing look-ahead windshear detection equipment(Ref. **3).** It was felt important to use the same model to

study crew interface issues as well as sensor development. The detection capabilities of sensors should take into account the expected pilot use of that information. Likewise, crew alerting systems should be aware of the limitations and capabilities of the sensors. The evaluation of both areas using the same model was a natural direction to take.

2.3.2 Test Procedures

The objective of the test was to provide an operational, comparative evaluation of various look-ahead alerting schedules (alert presentation times before reactive warning or microburst core), using both normal go-around procedures and windshear escape maneuvering. Eight look-ahead warning times, ranging (in 5-second intervals) from **22** seconds to 57 seconds before core encounter (1 to **36** seconds before the reactive alert) were used in the study. The test was conducted during a piloted encounter with low level windshear. The specific goals of the test were to evaluate the NASA windshear model, evaluate the functions of a time-critical alert given at various times prior to the core of a microburst, compare the two procedures for avoiding the microburst hazard area using look-ahead alerting, and to obtain pilot comments about the display/procedure concepts.

The test was conducted as a piloted evaluation in the Renton Flight Simulation Laboratory Engineering Cab Simulator. The **737-300** standard simulation model (with full EFIS instrumentation) was used. The aircraft was flown at maximum landing weight with a reference approach speed of **136** knots. The Boeing/Sunstrand reactive windshear detection system was fully operational throughout the simulations. This system alerts the crew by activating a red windshear message on the lower half of the EADI and a "windshear, windshear, windshear" voice annunciation. The look-ahead windshear warning was annunciated as a red windshear light bar located **3** inches to the right of the top of the EADI with a "windshear, go around" voice annunciation.

Five pilots flew each of the eight advanced warning times using both go-around methods. The schedule of advanced warning times was randomized and the display/procedure order was balanced to minimize the effects of anticipitory responses to the test conditions. The aircraft was flown fully coupled (autopilot and autothrottle) until the look-ahead windshear warning was given. The pilots were instructed to then depress the TOGA buttons, decoupling the autopilot, and to execute the appropriate procedure. This go-around procedure was either the standard go-around or the windshear escape maneuver spelled out in the FAA windshear training aid document (Ref. 6).

Each pilot was prebriefed and debriefed in the same manner. The oral checklist for the briefing given to each pilot is included as Appendix IV. After all of the pilot's questions had been answered, the simulator runs began. Each display and procedure was reviewed with each pilot before actually flying that test condition. After each simulator run a short subjective evaluation was conducted on that particular encounter. ***An*** example of the post-flight questionnaire is shown in Appendix V. After all the simulator flying **was** complete, the written questionnaire shown in Appendix VI was administered.

2.4 Windshear Display Formats

As information requirements begin to evolve from analysis and simulation work on alerting requirements, the need for various display formats will become clearer. This task explored potential display format candidates to support three areas of crew interface with the windshear environment: a) alerting, b) guidance, and c) status or situational awareness.

The type of display format and information needed for alerting will most likely depend upon the alerting level, and upon the crew procedures established for each alerting level. Thus this task assessed formats for display under the standardized alerting system guidelines, as well as formats to possibly be presented on the primary flight display (PFD). Formats that have been proposed in the past, or are used on current reactive systems, were examined as well as formats applicable to forward-looking windshear alerting situations. The most viable candidates were further developed for eventual evaluation testing in the simulator. Evaluations would consider primarily the effectiveness of the format in achieving its purpose, which would vary for different alerting levels.

Formats for guidance displays also were explored under this task. There could likely be two categories of guidance displays. The first might present very simplistic command information under conditions where the crew would follow a pre-determined flight manerver, e.g., a standard go-around. Secondly, some situations may require dynamic, highly sensitive flight director cues that would optimize the aircraft's potential to escape the windshear under severe in-situ conditions. This latter category of guidance format would depend highly upon performance characteristics of the aircraft, the threat level, timing of the alert, and phase/location of the aircraft.

Display formats were also assessed that provide the crew with windshear status information would Serve to enhance the situational awareness of the crew, and may therefore aid in decision making. For this task area, however, there is an added benefit in providing a mechanism by which the crew could assess the windshear threat before actually encountering the effects of the windshear. This could be used effectively in simulation tests where the pilot would choose alerting points based upon the forward-looking assessment of the threat. In this manner, several categories of alerting could be assessed within a single "run", with both pre- and post-encounter determinations of alert timing.

2.5 Crew Alerting & Procedures

This task consisted of taking a structured approach to the establishment of alerting criteria, the utilization of various alerting levels or categories, and of crew procedures to deal with look-ahead, as well as reactive, windshear alerting situations. The initial direction and scope for this task was provided by the NASA LaRC technical monitor for

the crew interface task, Dave Hinton. For a stepping-off point, the "Model of Flight Crew Actions" provided in the FAA's Windshear Training Aid (Ref **6)** seemed to be a logical selection.

In the long run, it is essential to organize this task such that there is consideration of the many diverse factors which may affect the ultimate design of the complete windshear crew interface. A starting point for this **task** was an analysis of current operational and training philosophy and procedures found in the Windshear Training Aid. The eventual desired product of this task would be **a** model of crew alerting and procedures in the look-ahead windshear environment that would be widely accepted and used throughout the user community. In this context, the model should also incorporate the requirements of reactive systems so that a smooth integration of these two can be accomplished. This task is primarily an analytical one, but should produce recommendations for testing of various aspects to verify their appropriateness or effectiveness.

One **of** the more important overall goals in the crew interface task area is to develop a philosophy of look-ahead **WS** alerting that integrates well with the philosophy, and with the criteria and procedures, of reactive (in-situ) WS detection and alerting systems. However, it is likely that, **as** look-ahead technology matures and on-board systems go through both simulation and flight tests, that reactive systems themselves will be upgraded and/or modified to better complement the capabilities of the look-ahead systems.

In discussing the models with various knowledgeable individuals, it became obvious that there were a variety of opinions in this area. In order to establish the best possible (most accepted) model, it was decided to further query both industry and the pilot community regarding this aspect of the model. A survey was then developed (included as Appendix VIII) to provide a structured format for inputs by those individuals (or groups) included in the survey.

The details of the development of the survey, and the responses received from its distribution, are reported in section ***3.5.***

3.0 ACCOMPLISHMENTS

The work completed during this phase consisted of: a) identification of critical crew-interface issues and development of an issues document; b) consideration of alerting system design philosophy; c) alert timing simulation testing; d) developing alternate concepts for windshear status displays, levels of alerting, and guidance displays; e) prototyping of the alternative display formats; f) development of a "straw-horse" model of alerting and crew procedures in the integrated reactive/look-ahead windshear detection environment; and g) administration of the survey to industry and the pilot community.

3.1 Identification of Critical Crew Interface Issues

3.1.1 Results of the Crew Interface Issues Survey

On-site interviews with technologists, manufacturers, pilots, airline companies, and regulatory agency personnel were used to determine the critical issues that should be addressed. There were 74 respondents to the issues survey as of the writing of this report, with a wide range of experience represented by the respondents, including technologists working on look-ahead windshear detection systems, manufacturers of present day windshear detection systems, pilots from various major air carriers, officials from regulatory agencies (FAA), Part-135 carriers, training departments of various airline companies and manufacturers, ALPA representatives, and members of the SAE S-7 Windshear Subcommittee. The top five issues rated as most critical for resolution before implementation of look-ahead detection systems were:

#1 - Missed alert acceptability;

#2 - The distance windshear needs to be seen in front of the aircraft so it can be avoided;

#3 - False alert acceptability;

#4 - Nuisance rate acceptability; and

#5 - Crew procedures to be used with look-ahead windshear detection systems.

These top five critical issues are represented in Figure 3.1.1-1. The comments raised by the survey were quite varied and have been summarized in a comments section located in Appendix II.

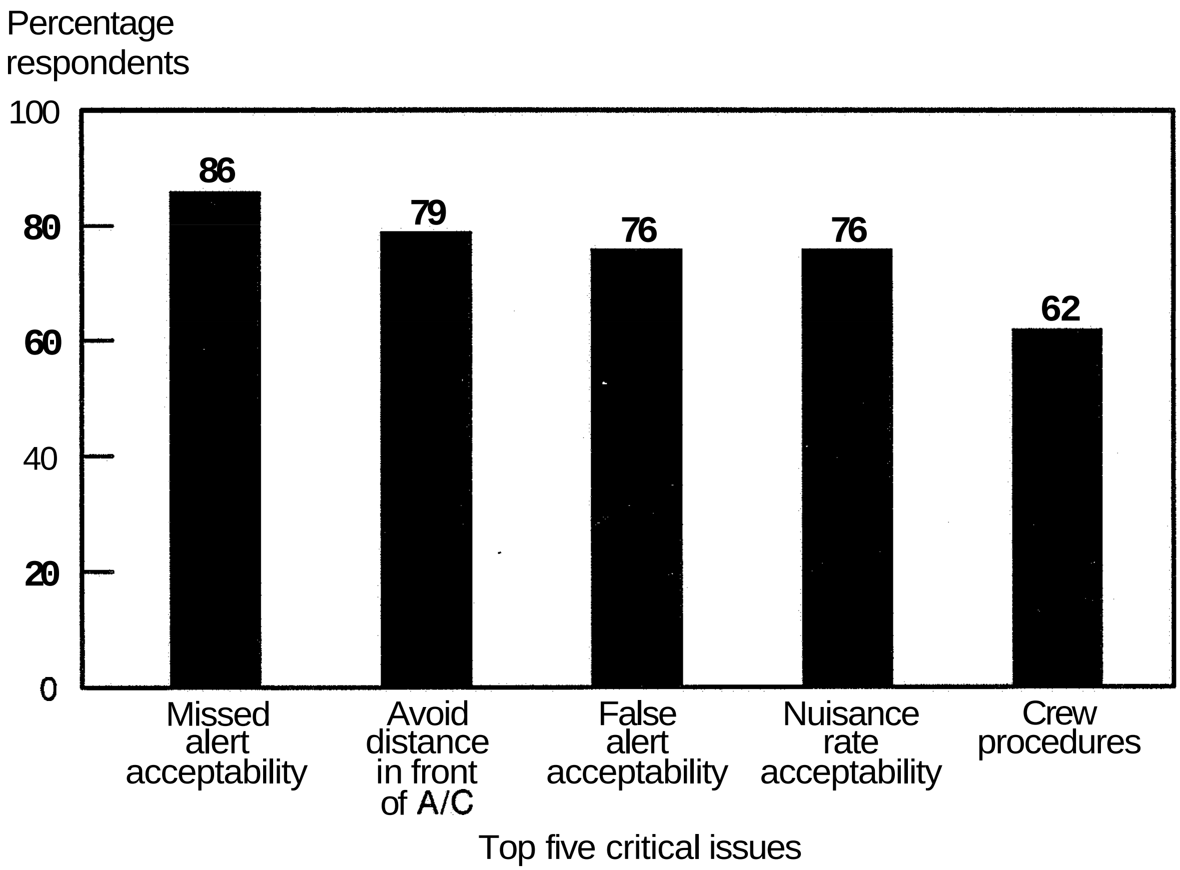

Figure** 3.1.1-1 **Windshear Detection Survey Results-Top Five Critical Items

3.1.2 Crew Interface Issues Document

The results of the issues survey were developed into a "Crew Interface Issues for Advanced Windshear Detection Systems" document, which is included as Appendix III. This document is modeled after the SAE G-10 TCAS Subcommittee document concerning human engineering issues involved with TCAS (Ref. 7). The objectives of the crew interface issues document were: a) to identify the current crew interface issues involving advanced windshear detection and avoidance; b) to categorize the issues relative to implementation impact and research priorities; c) to provide requirements for research activities to address the issues raised; d) to provide a methodology for systematically identifying areas of concern; and e) to provide a repository for the human engineering knowledge developed in support of advanced windshear detection systems. This document was developed on an IBM PC microcomputer using RBase System V database software. The benefits of this method were: 1) an extensive report generation capability; 2) information is easily retrieved and formatted to reduce the time used by those conducting research activities; and 3) the results of research conducted is easily accessible.

Although this database of crew information issues was structured for continued use, there are currently no provisions for keeping it up. There are presently 29 issues identified and categorized in the database. There is an issue identification system which can be used to search the database on any specific area. The format for documenting each issue in the database is shown in Figure 3.1.2-1. This format includes the name of the issue, its description, the requirements for the recommended or implemented approach, whether there is current activity concerning this issue, and any conclusions reached thus far. Within each implementation-impact category, an attempt was made to identify research priorities. The priority rating was based on the number of respondents identifying the issue as critical and the assessment of the Boeing Flight Deck Research group. The priorities were assigned as numerical values, with "1" being the highest priority level.

3.2 Alerting System Design Considerations

Developing a consistent philosophy for advanced windshear alerting is a difficult task that must take into account: 1) a variable and infrequent phenomenon, 2) evolving technological advances, and 3) the constraints affecting piloting tasks as they exist today and in the near future. An initial philosophy was developed for look-ahead alerting that would be consistent with these considerations, and with proposed system design guidelines and functional requirements.

3.2.1 Alertin? Philosophy

This proposed alerting philosophy, though consistent with present day alerting guidelines, by no means should be construed as definitive or supported by evaluation techniques or data. The preliminary nature of advanced windshear

Sequence No.: 01
Implementation Impact: Desired
Research Priority: **8**
status: **Open**

Windshear Detection Issues Identification

Issue Code: A43.000 Related Codes: A61.000

Entry Date: **03/09/88** Retrieval Date: -0- Update: -0-

Name of Issue:

Identification on Non-Critical Shears

Description:

Look-ahead windshear detection devices will have the capability to detect the display wind speed changes that would not normally be hazardous in intensity. These winds would be considered not hazardous based on low wind rate of change or magnitude of the change.

Requirements, Recommended or Implemented Approach:

Determine if non-hazardous wind information would benefit flight crew performance.

Current Activity:

1. Rolf Hanse, Boeing - reactive device improvements to account for energy management through non-critical shears to reduce nuisance alerts.
2. Dave Carbaugh, Flight Deck Research, Boeing - look-ahead display - non-critical shear presentation evaluation.
3. Russell Targ & Milton Huffaker, Lockheed/Coherent Technologies - Lidar effort, constant lidar readout of winds at 3 different distances in front of aircraft - used Lockheed display format to require evaluation by pilot - would see positive and negative shears.
4. E. Bracalente, NASA Langley - depending on Doppler shift threshold may be able to detect non-critical shears.

Conclusions:

-0-

Figure 3.1.2- 1 Crew Interface
Issues Database Format

detection look-ahead sensor technology, and our ever-increasing knowledge of the windshear phenomenon, makes this alerting philosophy subject to future revision.

Presently in the terminal environment, there are many sources for windshear information. These information sources have been categorized in the **FAA** Windshear Training **Aid** along with the hazard potential associated with each. These pieces of information are used by crews to make early avoidance decisions. Look-ahead windshear detection simply is another piece **of** information available in the avoidance arena. However, when these sensors are used to alert the aircraft, they *are* now interfacing as part of an alerting system and must be treated differently. On approach, it seems highly unlikely that an individual aircraft will be able to detect windshear in excess of ***5*** miles in front of the aircraft. Outside of this range, reliable information probably will not be present in the form of on-board alerting because of the variability of the event that may be detected or encountered.

Inside this range, in addition to information/alerting from a look-ahead system, valuable information may be received in the form of message traffic from plane-to-plane or ground-to-plane data sources. It may be in the form of a voice message or data transmission on an EICAS display such as "windshear detected **2** miles - approach end of DFW 17L - **35** knot shear". This is consistent with alerting system categorization guidelines that state that the "Information" level is consistent with "operational or aircraft system conditions that require cockpit indications, but not necessarily as part of an integrated warning system" (Ref. **8).** This region clearly promotes avoidance by proceeding to **an** alternate, holding, or at least using the proper tools to assess the situation accurately in a no-threat situation in order to make an avoidance decision.

The next region where an alerting philosophy may gradually evolve is between 5 miles from the microburst and approximately 1.5 miles. It is in this region that presently envisioned look-ahead systems will attempt to show long-range effectiveness. This is also the region where the windshear now presents a real threat possibility and crew action may be required despite the lack of previously received information. This region lends itself easily to be "Advisory" in nature. The criterion for an advisory alert is: "an operational or aircraft system condition that requires crew awareness and may require crew action" (Ref.8). Information can be displayed for the pilot to assess the situation. At the same time, the windshear detection system can further evaluate the windshear to improve it's reliability. The options for the flight crew can be quite variable depending upon how early the advisory alert is received and upon the ATC environment. The pilots should not use this advisory as **a** "head's up" indicator for them to then wait for a warning. The windshear system is telling the pilot that the threat detected is actually there and is severe enough presently to warrant avoidance. However, immediate action is not required ***so*** avoidance options can be exercised.

Inside of approximately 1.5 miles, the alerting should probably be in the form of a "Time-Critical" alert that requires immediate awareness and immediate response. The distance of 1.5 miles is selected to approximate the time/distance function where an immediate response is required to avoid the windshear area critical to safety of the flight.

This does not necessarily mean the aircraft will avoid the phenomenon altogether, but with a straight-ahead maneuver, will at least avoid the most hazardous region of the windshear or face only a low-energy encounter.

A "Caution" area between the time-critical and advisory alert levels is not recommended at this time. A caution alert requires "prompt" action which is usually accompanied by a procedure the crews must follow. If such an alert were to be used in this case, the caution message might require a straight ahead go-around at somewhere between 5 and 1.5 miles. However, a lateral maneuver (assuming ATC clearance) may have been more appropriate or the aircraft perhaps would have flown completely above the hazard and crews would thus think of the alert as a nuisance. The options that may be exercised because of a caution are many and may result in unnecessary delays and/or inaction.

Reactive systems should still function normally and will be an essential part of any advanced windshear system. They provide a positive warning system once the windshear is encountered and require a windshear escape maneuver. The termination of look-ahead alerting should occur at a combination of power setting and altitude such that the pilots have successfully avoided or dealt with the hazardous area, or until the hazard is no longer sensed as a threat. One possible configuration would be to use 1000 feet AGL with go-around thrust.

The takeoff situation presents unique alerting challenges for look-ahead systems. Because performance is usually limited and avoidance options in the threat area even more limited, the look-ahead system should be strictly a "warning" system. Ideally these systems should allow an evaluation of the windshear threat prior to the takeoff roll and should issue a warning if the threat exists. This may require effective detection ranges of approximately 3.5 miles for heavyweight 4-engine transports. However, it is not recommended that look-ahead alerts be given on the runway <u>during</u> takeoff roll. The extreme variability of conditions present during takeoff roll in many cases will make the indecision and possibly aborted takeoff more of a hazard than the windshear would have been. The windshear accidents to date involving takeoff situations have all had some sort of wind indications of a hazard during the takeoff roll, and these should be detectable by a look-ahead system before takeoff roll is initiated. Thus, look-ahead systems should strive to be able to alert crews prior to the takeoff roll and should present coverage of at least the takeoff roll length. The termination of windshear warnings on takeoff should occur in the same manner as approach warnings were terminated.

3.2.2 Alerting System Functional Requirements

A new windshear detection system that incorporates look-ahead technology should follow the basic alerting guidelines developed and in use today in modem transport aircraft (Ref. 8). The basic function of the advanced windshear detection alerting system should be: 1) to attract the attention of the flight crew and direct that attention to the windshear condition so that appropriate action can be taken; 2) to inform the flight crew of the location and nature of the windshear detected, and to provide sufficient

information to enable the crew to initiate timely, appropriate action; **3)** to provide the crew with a method to control the system to enable them to accurately assess the situation.

The alerting system should attract the crew's attention to the windshear situation, but should not be so disruptive that it degrades other crew **task** performance, information processing, or the decision making required to **assess** the avoidance decision. The system should **be** structured so that in time-critical situations, the alerting presentation commands immediate crew attention and crew recognition of the required crew action.

Because of the evolving new technologies, an advanced windshear alerting system should be designed to allow future growth and modification with minimal effort. This system flexibility will be a highly desirable feature especially when, as in any evolutionary process, original design thresholds, operational procedures, or presentation techniques may be proven inadequate or less desirable when compared with later developments.

3.2.3 Alerting System Components and Integration

To accomplish the functions described above, the components of such an alerting system should include a master visual and aural alert, designed to attract the crew's attention to any situation requiring immediate crew awareness and to provide a preliminary indication of the alert urgency level. An "alert display" should be provided to indicate the specific alert, its urgency level, and its chronology. **A** visual information display should present information necessary to solve advisory level information problems that may be available from several sources (airborne, ground, other aircraft). The visual information display may take several forms, such **as** a radar overlay, vertical situational display, or others. Lastly, a time-critical display format will provide the crew with information concerning the nature of the problem and specific guidance for the necessary immediate action.

The presentation of all alerting signals should be accomplished via a single integrated alerting system when aircraft configuration allows. If retrofitted into older generation aircraft, the alerting system should be modified to reduce confusion and alerting proliferation. The problem develops as aircraft and their associated systems become more sophisticated, and new alerts and alerting devices are added with little regard to integration philosophy.

3.2.4 Alert Urgency Level Categorization

To maintain consistency with the proposed alerting philosophy, the advanced windshear alerting should be restricted to only those levels of alerting categorization (of the four available), that can be demonstrated to satisfy unique threat levels and resolution schemes. Two of the most likely levels are "time-critical" and "advisory". These levels require either an immediate action to go around or provide time to evaluate and perhaps

take subsequent action. The "caution" level falls between these two and requires immediate awareness and prompt corrective or compensatory action. It is possible that this level of alerting may cause a delayed response on the part of crews, losing valuable time needed to adjust energy to penetrate windshear situations based on present sensor indications.

3.2.5 Other Design Considerations

Alerting Reliability - The alerting component should be designed to reduce the pilot's workload by always(goal) presenting valid and reliable information. The windshear alerting system should be activated only when a valid windshear threat exists and false or nuisance alarms should be minimized, Frequent false or nuisance alarms not only add to aircrew workload, but also contribute to the pilot's failure to detect and correctly interpret a real indication. Confusion between predictive and reactive alerts should also be avoided.

Informational Displays - The format and content of information displayed must be clear, concise, and unambiguous. The display should be located to facilitate the crew's response to the alerting situation. The physical characteristics of the display should facilitate the transfer of windshear information to the crew, and the display should be operable in all expected ambient light conditions.

Voice Messages - The voice characteristics should be highly distinctive and intelligible. Voice messages should be presented using a monotone inflection and should be presented at an intensity of *5* to 11 db above the ambient noise level. For time-critical warnings, the alerting signal and essential elements of the voice message should be conveyed in *2.5* seconds or less (Ref. 8). For time-critical warnings, the voice alerts should provide guidance information.

Alerting Priority - Where feasible, a prioritization scheme should be incorporated to enable the crew to receive the alert appropriate to the required awareness and response. An example would be the reactive system and the look-ahead system sensing a windshear at the same time. In this case the appropriate alert would be the reactive system alone.

3.3 Alerting Simulation Study

Several simulation runs were conducted to observe initial uses of look-ahead windshear alerting. Although the testing was limited in scope, the obvious benefit of advanced warning was appreciated by all of the pilots, and was also evident in the data.

3.3.1 [illegible]

Each pilot was asked to judge each windshear encounter as to the timeliness of the occurrence of the time-critical look-ahead alert. The three response categories used were defined as:

"Late"--the alert occurred at a point that the phenomenon encountered and/or the flying skill required to transit and escape the hazardous windshear was such that the margin of safety was degraded to the point where the warning was felt to be too late to be adequately effective or desired of a look-ahead system;

"Early"--the alert occurred at a time where excess energy was available in comparison to the windshear encountered. A reduction in alerting time would be appropriate to allow increased sensor evaluation time in an effort to reduce nuisance alert problems;

"About Right"--Look-ahead warning occurred at a point that provided an adequate advanced warning time that was neither too late nor too early.

An additional subjective measure involved the pilots' termination of the simulation run at a point where they considered the look-ahead warning indication to no longer be required. This point was recorded for each data run. The objective data was measured as a comparison with time of: calibrated airspeed, pitch angle, ground track location, vertical speed, radar altitude, wind components, engine indications, wind rate, and F-factor encountered. The alerting simulation objective and subjective data are summarized in Appendix VII.

3.3.2 Data Analysis

The data was analyzed and conclusions made with the knowledge that this simulation testing had several limitations. Absolute realism cannot be attained in testing of non-normal situations. In this case, the pilots all knew the purpose of the test and that a windshear would be encountered in every case. The conclusions resulting from this simulation testing apply only to the 737-300 (at maximum landing weight), flying a windshear encounter simulated by the NASA windshear model. Alert timing and pilot perception and performance will most certainly vary depending on aircraft performance capability and the windshear encountered. However the variability of the windshear phenomenon makes such broad scope testing to cover all the variables impractical.

3.3.3 Conclusions

The following represents the subjective and objective conclusions reached after analysis of the simulation and opinion data:

1) The pilots thought that the windshear model flown lacks the turbulence and roll transients expected in such a severe windshear encounter;

2) The pilots felt that the windshear model was severe;

3) The look-ahead warning as presented was easily distinguishable and prompted immediate appropriate action. Objective data confirmed that the pilots response to the alert was typical of that anticipated with time-critical alerts. Pilots favored **an** **EADI** integration of the alert for glass cockpit aircraft;

4) All of the pilots favored the normal go-around procedures for use with the look-ahead alerts(lateral avoidance maneuvers were not required, nor used);

5) Look-ahead alerting timing subjective opinion was not related to the maximum F-Factor encountered;

6) In 90% of the cases where the look-ahead warning was given **32** seconds prior to the core **(11** seconds prior to the reactive alert), the pilots considered it to be too late to be considered **an** effective look-ahead system;

7) In 90% of the cases where the look-ahead warning was given **57** seconds prior to the core **(36** seconds prior to the reactive system), the pilots considered it to be given too early and that a look-ahead system could spend more time evaluating the phenomenon rather than giving an alert that early;

8) The average warning time considered to be appropriate for a look-ahead warning was **44** seconds prior to the core **(23** seconds prior to the reactive alert);

9) Pilots used the wind arrow extensively as a tool to evaluate the look-ahead alerting and as a means of understanding the hazard(between the alert and the core, they would observe the wind arrow responding as appropriate to the wind variations expected in a windshear event); and

10) In **46%** of the look-ahead go-arounds, sink rates were experienced below **200** meters radar altitude using the **FAA** windshear escape maneuver. In **17%** of the look-ahead go-wounds, sink rates were experienced below **200** meters radar altitude using the normal go-around method.

3.4 Windshear Display Format Alternatives

A number of potential display formats were developed for depicting the various characteristics of windshear that might be sensed by the forward-look detectors, or developed from processed data.

3.4.1 Format Considerations of Alert Levels

The type, format, and characteristics of displays to accompany forward-looking windshear alerts are, to a great extent, linked to the criteria for alerting (windshear threat level) and to the procedures determined to be most appropriate to each alerting level. **As** described in the section on the "Crew Alerting/Procedure Model", there are four levels of

alerting that were considered *to* be potentially useful to an integrated forward-looking/ reactive windshear detection system. It is yet to be determined whether there is a viable role for each of these alerting levels in addressing the windshear/microburst threat (e.g., in section *2.5* it was suggested that use of the "caution" level might not be appropriate). Therefore, the display requirements for each alerting level cannot yet be determined. However, some general relationships can be determined and the associated options **studied,** both on an analytical basis, and in simulation tests.

Crew response requirements were developed from those recommended for three of the four levels of alerting provided in an earlier alerting systems guidelines document(Ref. 8), **as** presented in Figure **3.4.1-1** These descriptions have been slightly modified from guidelines to incorporate the time-critical alert level, and **are** summarized below.

Alert Level	Crew Response Requirements
ADVISORY	Requires prompt crew awareness and may require Subsequent or future crew action;
CAUTION	Requires **immediate** crew awareness and **subsequent** corrective or compensatory crew action;
WARNING	Requires immediate crew awareness and **rapid** corrective or compensatory crew action;
TIME-CRITICAL	Requires immediate corrective or compensatory crew action, usually consisting of a flight path maneuver.

It should be pointed out that these four alerting levels are not all used on most, if not all, current aircraft, and their use in this study was of an "exploratory" nature.

1) ALERTING **CHARACTERISTICS** - Figure **3.4.1-1** lists the alert system characteristics for each alert level. In the current philosophy of alerting, each alert display element or aural segment is assigned a priority for display *to* the crew that is appropriate to the assumed need to gain the attention of the crew and provide rudimentary "awareness". For warning and caution alert levels, this has consisted of the illumination of the Master Warning/Caution Indicator, accompanied by an attention-getting aural sound, with a corresponding voice message being pilot-selectable. For advisory alerts, there is a unique aural sound, but no master alert or voice message. For all three levels, the alert title is displayed on a centrally-located visual display. The alerting characteristics for time-critical alerts have not been universally established. In practice, however, these situations have resulted in unique aural sounds, an automatic voice message, and a forced display of the alert title on the primary flight display since these alerts almost always require an immediate aircraft maneuver **as** the crew response.

2) ADVISORY DISPLAYS - These will primarily convey "situational awareness" information since there is **no** requirement for either immediate or rapid crew response.

Condition	Criteria	Alert system characteristics		
		Visual	Aural	Tactile
Information	Operational or aircraft system conditions that require cockpit indications, but not necessarily as part of the integrated warning system	Discrete indication (green and white)	None	None
Advisory	Operational or aircraft system conditions that require crew awareness and may require crew action	Centrally located alphanumeric readout (unique color)	Unique attention-getting advisory sound	None
Caution	Abnormal operational or aircraft system conditions that require immediate crew awareness and require prompt corrective or compensatory crew action	Master visual (amber) plus centrally located alphanumeric readout (amber)	Unique attention-getting caution sound plus voice*	None
Warning	Emergency operational or aircraft system conditions that require immediate corrective or compensatory crew action	Master visual (red) plus centrally located alphanumeric readout (red)	Unique attention-getting warning sound plus voice*	Stick shaker (if required)

*Voice is pilot selectable.

** Data based on Reference 8; see reference sources, section 5.0, pages 73 and 74.

*Figure **3.4.1-1** Alerting System Categorization* **

The information does not need to be automatically displayed without crew initiation, but can be selected by the crew. However, ready access is needed, since prompt awareness is required. It is also implied that these displays will be depicting information that may become more relevant or critical at some future time. This could either stem from an event taking place far ahead of the aircraft or from an event with a very low threat level;

3) CAUTIONARY DISPLAYS - These displays are probably "forced" only to the extent of providing the alerting essentials to the crew "immediately". Traditionally, this includes information on: a) what the problem is, and b) what system or function of the aircraft is affected. Since crew action is "subsequent", the information on what action is recommended is likely still to be selectable by the crew rather than forced. Since the action is not required immediately, it may also consist of pre-determined procedures or aircraft maneuvers that can be called (or looked) up by the crew;

4) WARNING DISPLAYS - Since these alerts require both immediate awareness and rapid response by the crew, any relevant information probably needs to be automatically displayed or made very readily accessible to the crew. If the required immediate response consists of only a few, reliably constant procedural steps or a standard maneuver, they (it) may not be displayed at all, but be relied upon as a "memory" item. Also, this information will primarily be "command" or "guidance" in nature rather than simply depicting status for situational awareness;

5) TIME-CRITICAL DISPLAYS - This category nearly always requires an immediate aircraft maneuver as the primary crew response. Therefore, the information will be command or guidance in nature and will be "forced" (highest priority for display) to the flight deck, probably on the primary flight display.

The sections that follow describe potential formats that have been developed or that are probable options for each of the above alert categories. Rather than being listed according to alert level, however, they are arranged by the nature of the information and its use by the crew.

3.4.2 Sensor Data Displays

This category of display supports primarily situational awareness for advisory and perhaps caution alerts. In addition, these may be employed for information displays in the absence of any related alert. For the depiction of windshear-related status information, these displays would depict a direct graphic representation of weather information that would hopefully correlate with microburst formation.

A number of methods have been developed by researchers for the processing of weather/microburst data for display on CRT's. These display formats were not initially intended for airborne display but for ground-based interpretation by meteorologists or ATC personnel, who could then relay specific information to the flight deck of aircraft that might be affected by the shear. However, if the formats proved to be quickly

processed, and easily interpreted, they could become candidates for on-board display, either from comparable sensors on the aircraft, or from data-linked, ground-generated data.

Figure 3.4.2-1 depicts one such format developed by the NASA Langley Research Center(Ref. 9), in which radar returns from a simulated airborne doppler radar have been processed into two separate formats, one representing horizontal wind flow data, and the other a further-processed format depicting the calculated windshear hazard index values. While these formats may represent the wind fields quite well, they are probably too complex to be easily interpreted by flight crews while initiating an approach. However, a foundation for displaying the overall hazard in the unified form of a hazard index or "F-Factor", has been well-laid in the work of NASA researchers(Ref. 10).

In Figure 3.4.2-2, both gust front data, and microburst icons are represented. This image, developed (by the National Center for Atmospheric Research - NCAR - Ref. 11) from real data from the TDWR(Terminal Doppler Weather Radar) system, was gathered during the series of microburst occurrences at Stapleton Airport outside of Denver, CO, on 11 July 1988. Obviously these microburst icons would be easier to recognize by an approaching crew than would raw data displays; however, their usefulness would depend upon their reliability, accuracy and timeliness. In addition, it is questionable whether an approaching crew would have the time to continuously monitor such a display.

Since the displays depict information for situational awareness rather than command or guidance information, the primary flight display is not likely to be utilized for this information unless it offers some unique advantage. The more likely candidates are the navigation display and one of the EICAS displays (for "glass" equipped flight decks).

3.4.3 Nav Disnlav Microburst Icons

The navigation (map) format typical of EFIS displays used on advanced Boeing flight decks could be used to display a variety of microburst characteristics, including location, size, strength, intensity;, direction of movement, speed, max winds, shape, etc. This type of display was therefore selected as the basic background for development of a series of icons to depict a number of microburst characteristics.

The basic icon shape used to represent a microburst on this display was a filled circle. Characteristics of the microburst that were selected for coding included location, strength, size, intensity, direction of movement, and speed. These characteristics were selected partly on the basis of the survey conducted by Hansman and Wanke (Ref.12), and partly from the need to explore any feature that might contribute positively to situational awareness or to the decision-making process of the crew. For each characteristic, several coding alternatives were developed so that alternatives could be evaluated. The characteristics were defined as:

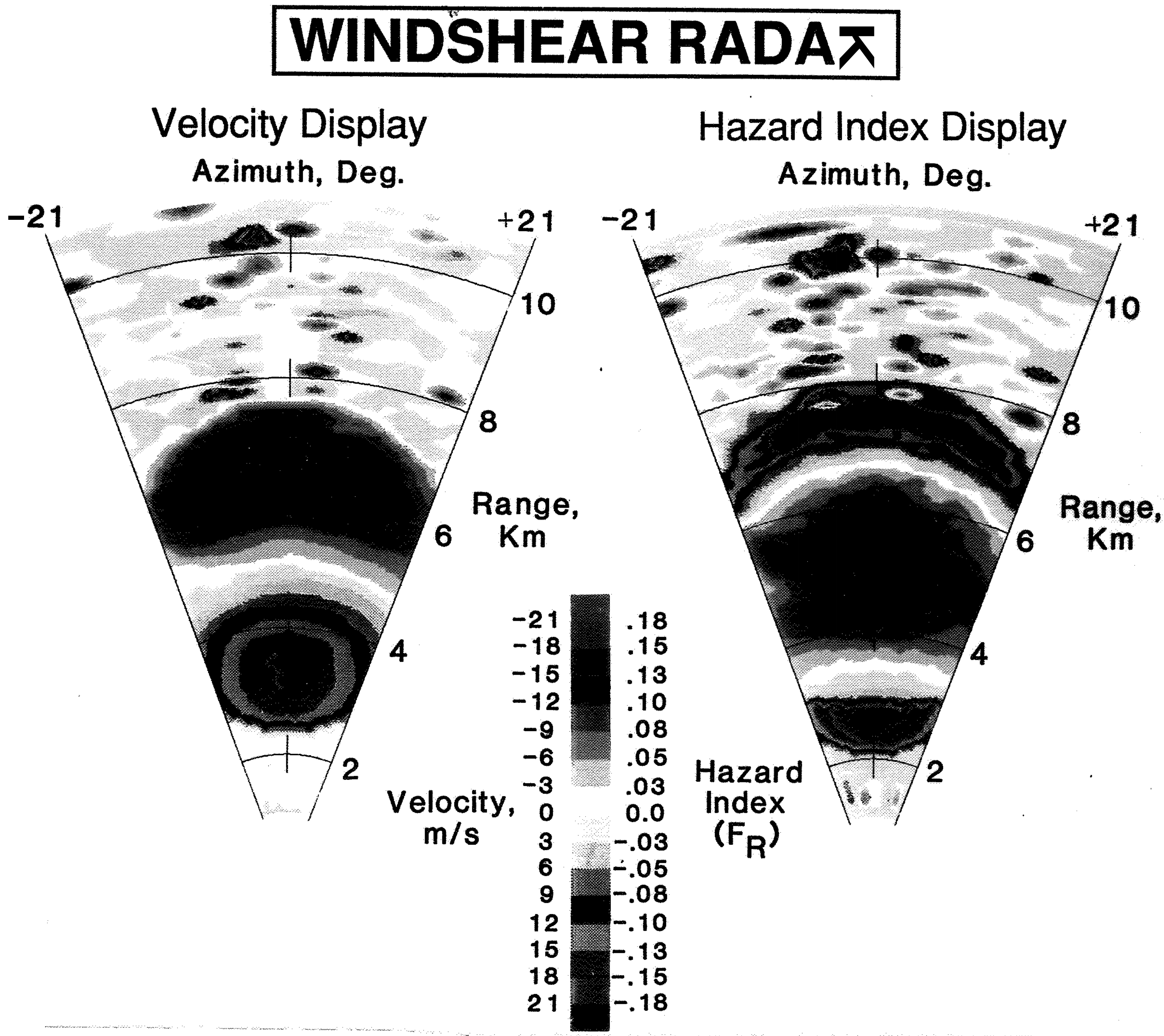

Figure 3.4.2-1 Processed Radar Returns for Windshear Velocity and Hazard Index Displays

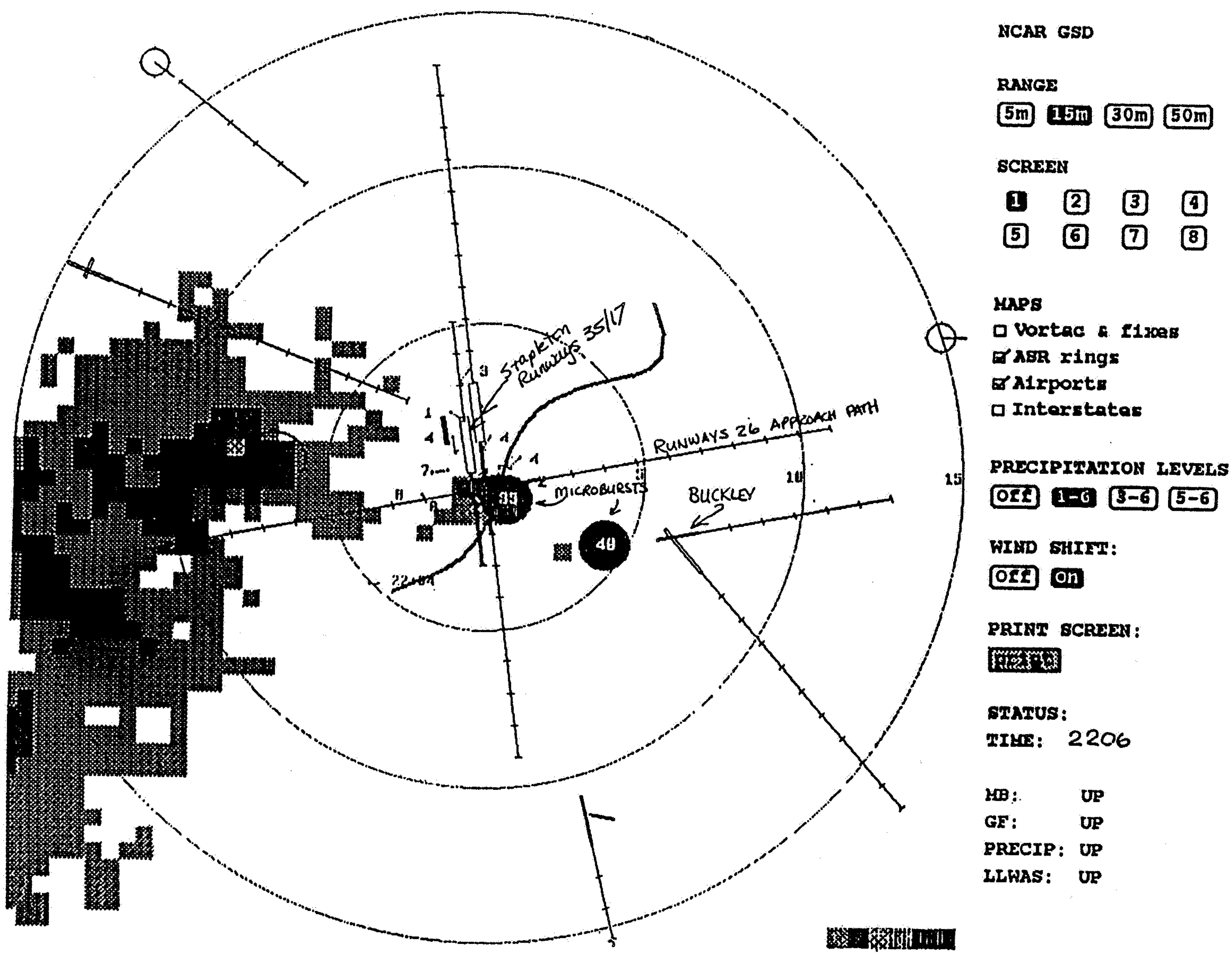

Figure 3.4.2-2 Microburst/Weather Display ▪ TDWR Data

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a) size - either the distance between peak "headwind" and **peak** "tailwind" at max-velocity altitude, or the distance between corresponding threshold wind levels;

b) strength - the max-headwind to max-tailwind differential;

c) intensity - this was represented by the combination of size and strength;

d) location - by position on the map display;

e) direction of movement - several icon elements were developed, including a "pointer", a "trail", a "history wave", and a "history shadows".

f) microburst speed - this was indicated by the spacing of the "history" elements in e) above.

The specific forms of the icons developed can be seen in several photos taken from the **DDS** display system. Figure 3.4.3-1 shows a circular icon, the diameter of which represents the "size" of the microburst. One alternative to be evaluated was whether the diameter of the icon should represent the "peaks-to-peaks" horizontal wind values, or a "threshold-to-threshold" concept, e.g., from 30 kts tailwind to 30 kts headwind.

The differently colored rings represent the strength of the microburst in terms of horizontal wind-intensity ranges. For example, if each ring represented a 20-kt intensity, the displayed icon would be depicting a microburst with a max horizontal wind intensity of 60 kts above the threshold value (it's assumed that the icon would only be displayed if its wind intensity were above a certain minimum threat value).

The triangular "pointer" was one concept of depicting the direction that the microburst is moving, but its speed is not represented in this particular format. Another concept for direction of movement is shown in Figure 3.4.3-2, where the direction of microburst movement (if available) is shown by a series of "history shadows". Similarly, the history "waves" shown in Figure 3.4.3-3, and the history "trails" shown in Figure 3.4.3-4 were other methods of depicting the direction of the microburst.

Since the "shadows" and "waves" represent the locations of the microburst at three equal time intervals in the past, e.g., 20, 40, and 60 seconds, the speed of the microburst can also be inferred from these formats -- from the separation between the segments of the shadows or waves.

Figure 3.4.3-3 uses a solid-color icon with an enclosed number to indicate wind intensity, or differential, or some other measure of microburst threat level. The color could either be neutral, by being the same for all microbursts, or could also be used to code the strength of the microburst.

All of the above characteristics were coded as variables which could be changed quickly either at the DDS station or in the simulation cab. In addition to the icon variables, the

simulation was designed so that a microburst could be initiated at a selected location, begin to develop at a selected rate and at a predetermined time into the flight, build in intensity for a period of time (selectable), and then dissipate, again at a selected rate.

3.4.4 Persoective PFD Displav

An alternative to displaying microburst icons or characteristics on the nav/map display would be to use the Primary Flight Display (PFD) for this purpose. Potentially, there are a couple of advantages: a) the situational awareness information would be on the same display as elements of the alerting sequence and guidance (if provided); b) the perspective format of this display may provide a more easily interpreted WS display than is possible on the nav/map display.

A perspective PFD format developed under IR&D was selected as a background format for development of a perspective microburst icon. This icon was constructed by rotating a single line segment around a vertical axis -- no hidden-line algorithm was used. Figure 3.4.4-1 depicts the icon as placed on the perspective PFD background. Variables were included to change the size (diameter) and height of the microburst, along with its location and AGL position. Finally, the perspective size of the icon is driven by the closing distance to the approaching aircraft, the effect of which can be seen in Figure 3.4.4-2.

Once the perspective microburst icon was completed, subjective evaluation revealed several potential problems with interpretation of this icon. Perhaps because a hidden-line algorithm, or background occluding, was not used, it was difficult to determine the exact fore-aft position of the microburst. This was even more difficult if the base of the icon was not located at ground level. This problem was helped somewhat by positioning a solid, circular "base" on the "ground" surface, but the perspective at 3 degrees or so did not lend much definition to this additional element.

3.4.5 Energv Forecast Disnlav

As mentioned earlier, one purpose of a situational awareness display could be to provide, on an ongoing basis, a prediction of the effects that a detected microburst, and its future encounter, would have on the flight profile or energy state of an approaching aircraft. Simply put, such a display would attempt to answer the pilot's question (for example): "If I continue my approach, what effect will this microburst have on my ability to land safely?" Obviously, this question, and the associated display, are only relevant if the pilot is not following a philosophy that dictates: "abandon an approach if any windshear (microburst) is detected",

Note that this is not necessarily the same as a philosophy of "avoid any hazardous windshear". One can envision a possible situation where a microburst, detected say 45 seconds ahead of the aircraft and exceeding (at that moment) an alerting threshold, might

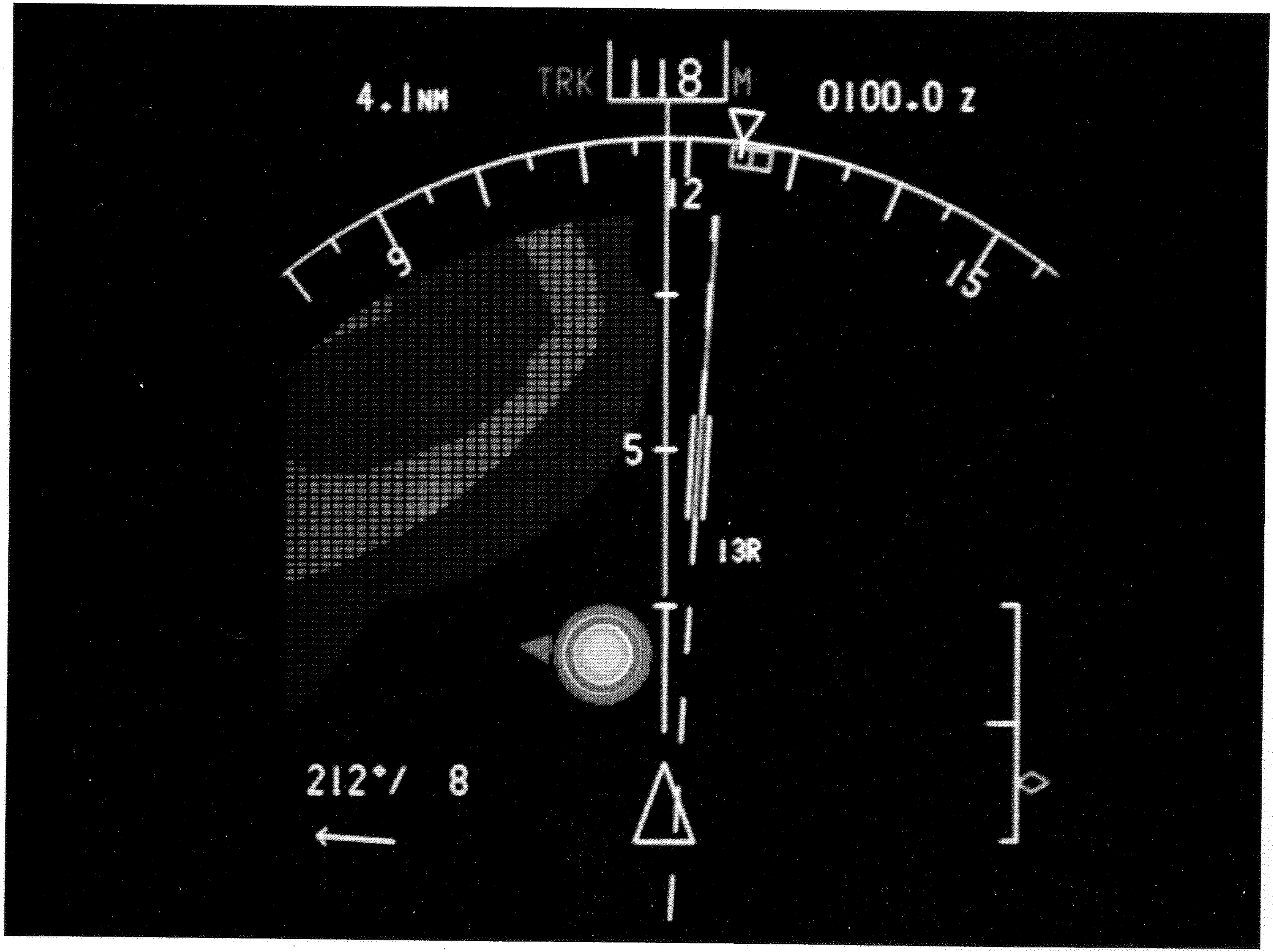

Figure 3.4.3-1 Microburst Icon with Direction Pointer Element

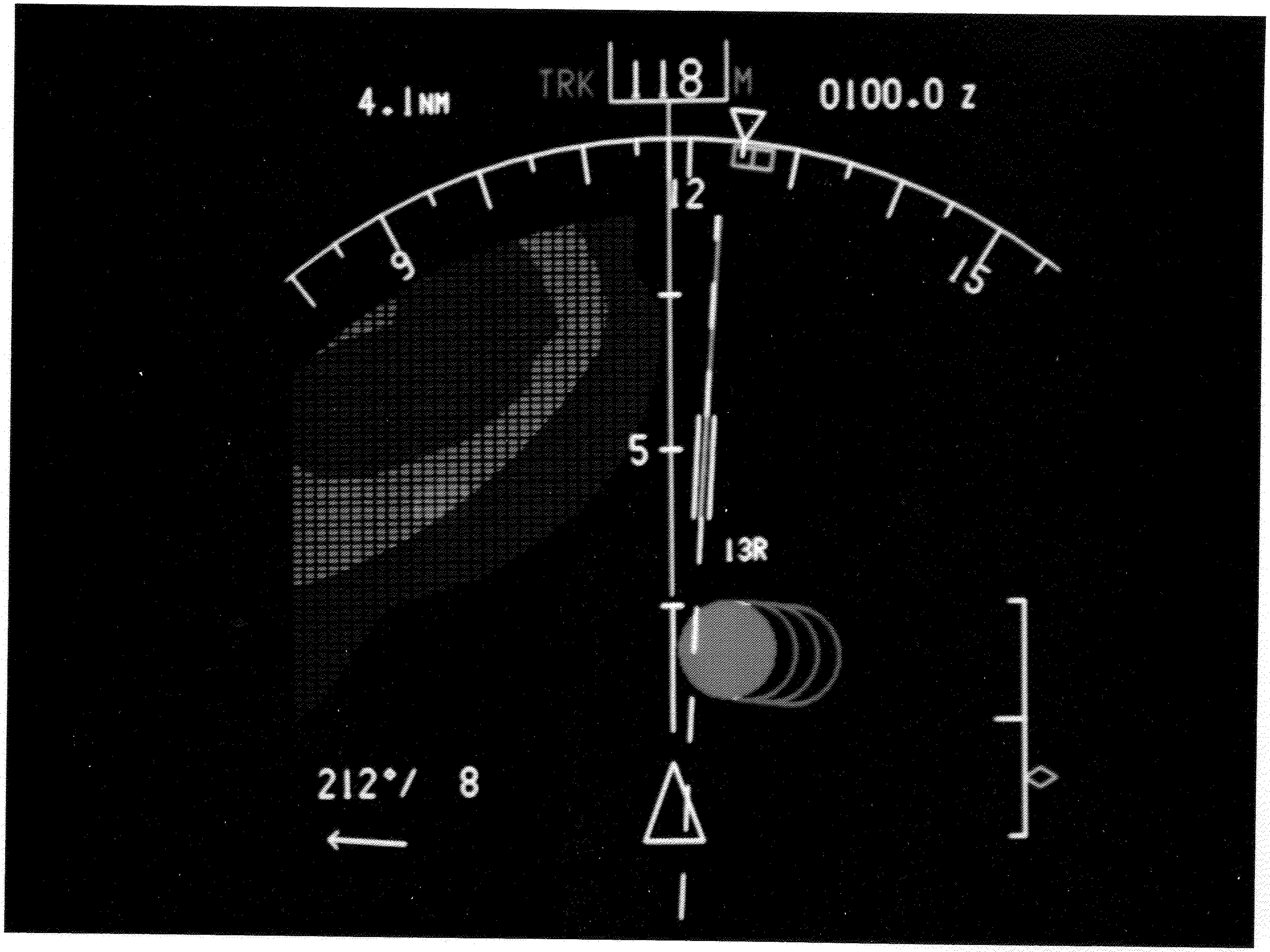

Figure 3.4.3-2 Microburst Icon with History Shadows

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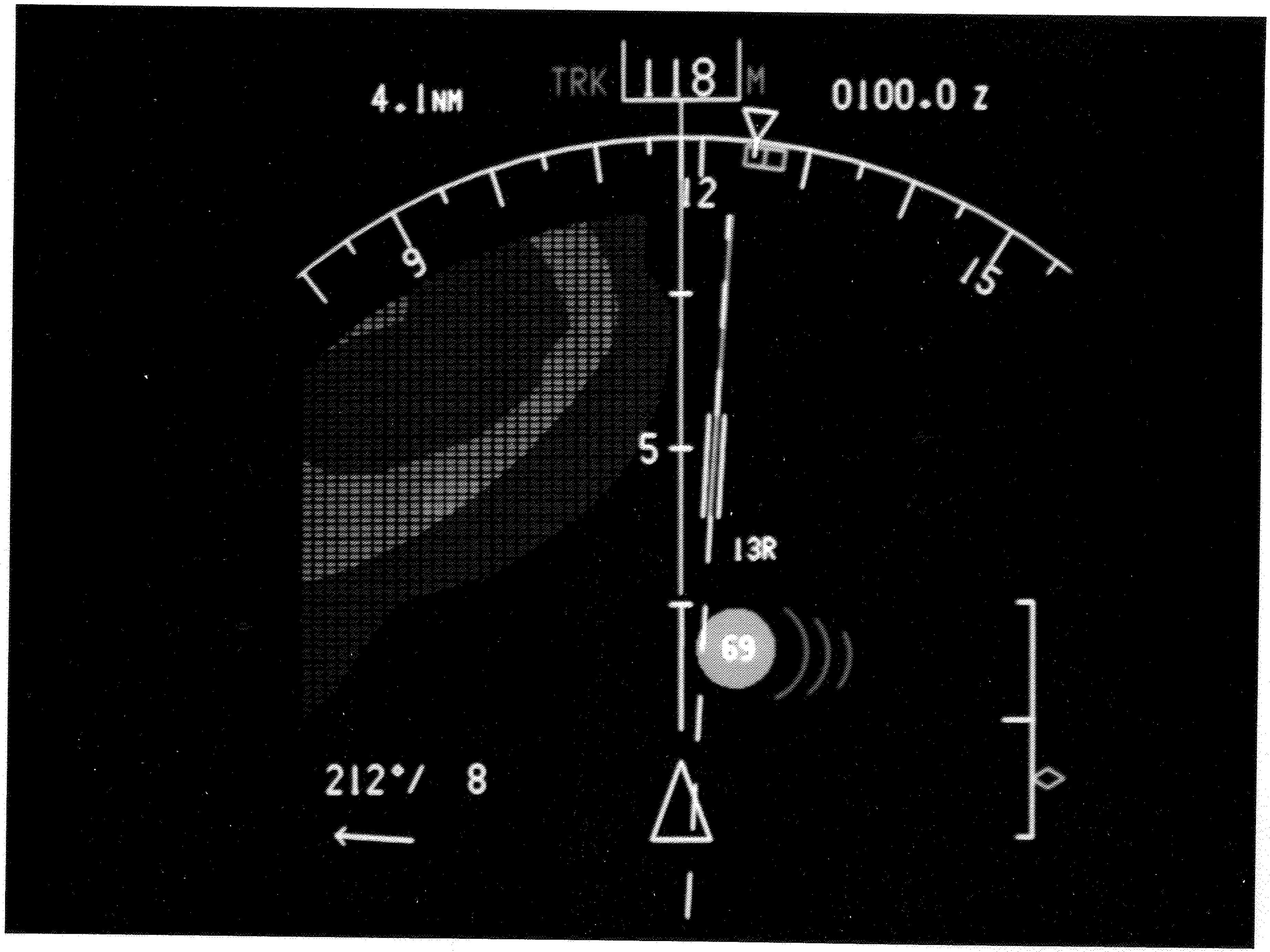

Figure 3.4.3-3 Microburst Icon with History Waves

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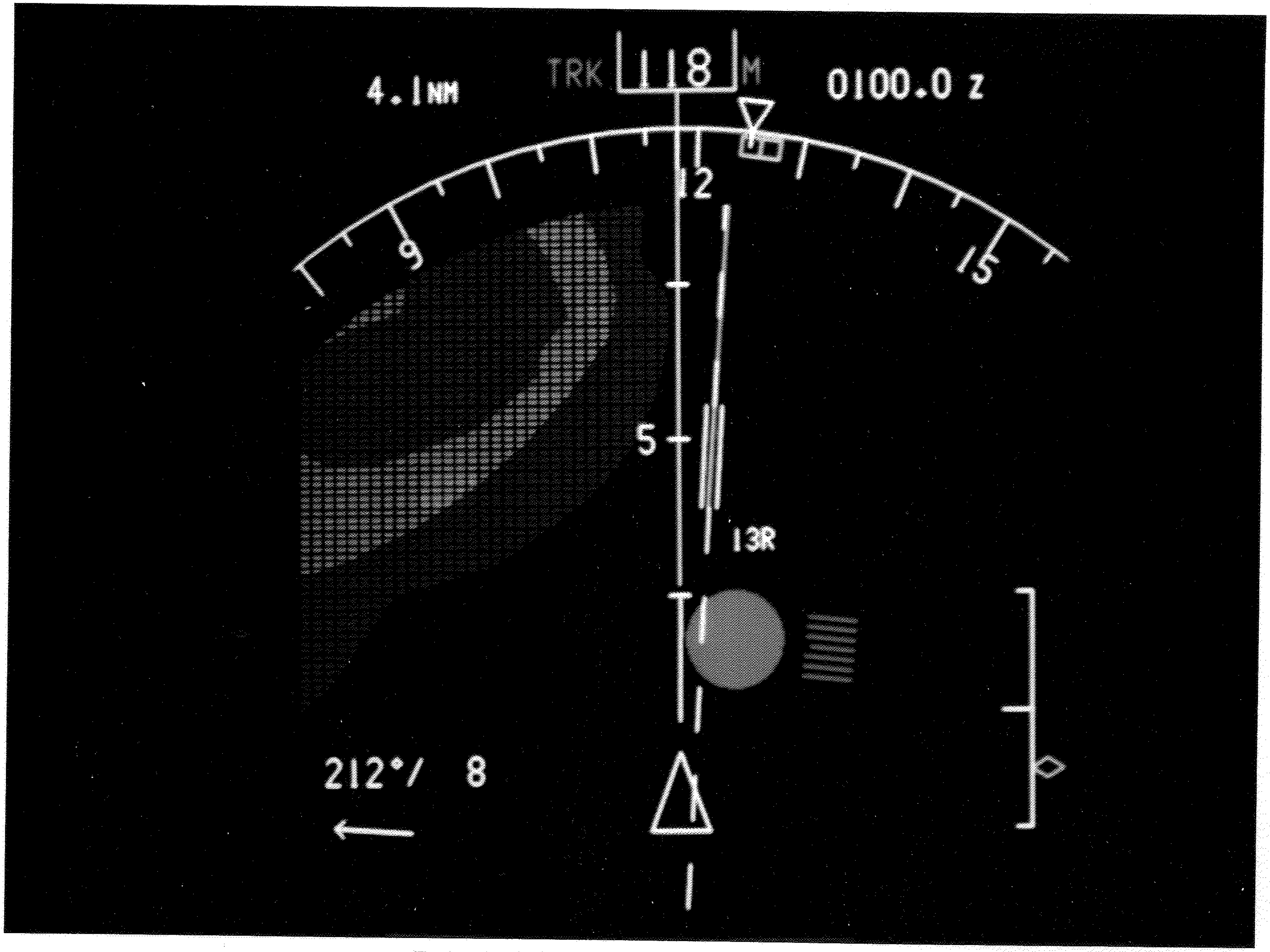

Figure 3.4.3-4 Microburst Icon with History Trail

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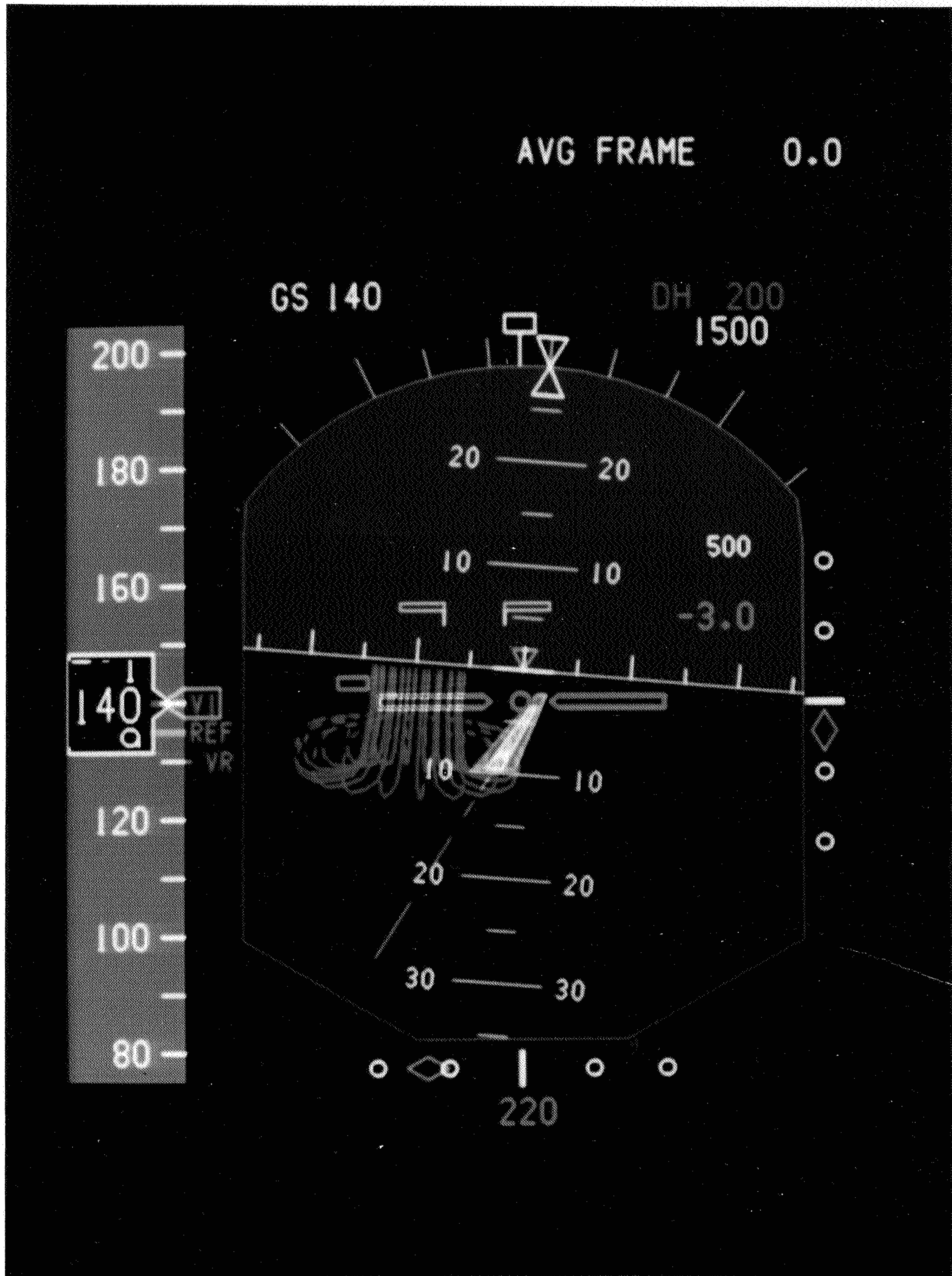

Figure 3.4.4-1 Three-Dimensional Microburst Icon on Perspective PFD

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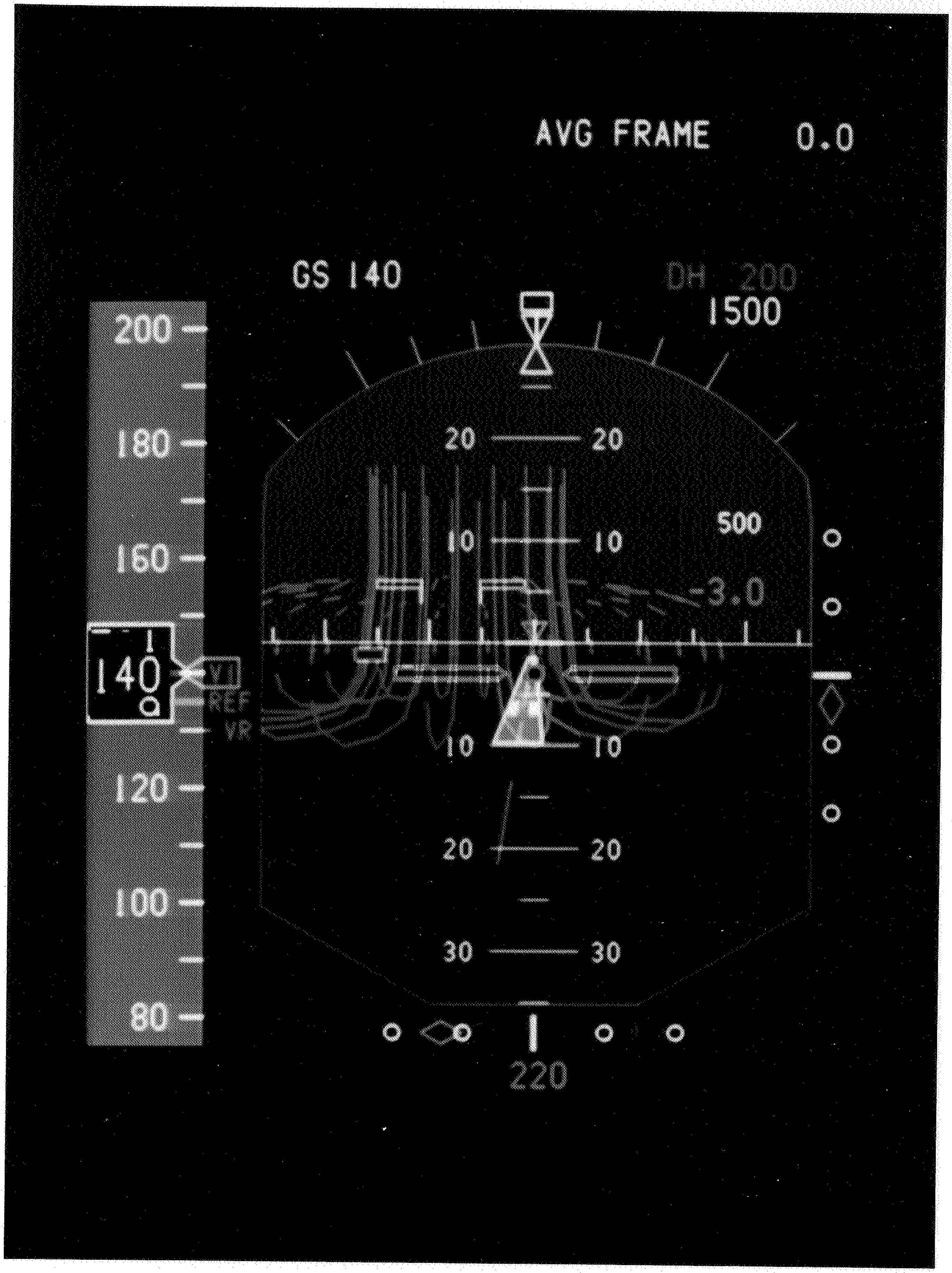

Figure 3.4.4-2 Perspective PFD Microburst Icon at Close Range

not have a significant effect on the aircraft 45 seconds later if the pilot were to continue the approach. Now if the pilot is alerted, and abandons his approach without further evaluation, he would be responding to what could be described as a "nuisance" alert (because the predicted threat would not have materialized), If he were provided with a display showing the predicted effect at some future point in time, he might choose to continue an approach for a number of seconds while evaluating the trend of the microburst threat, even if he ends up abandoning the approach.

Whether this is a viable option is certainly an open question, and one that needs to be explored, and resolved if possible, in simulation studies. Certainly there is current thinking that intentionally delaying the abandonment of an approach where there is a detected threat would be a foolhardy (dangerous or risky) choice.

One display format that could be designed to provide predicted-effect information might be based upon the Vertical Situation Display developed for the Boeing "7J7" preliminary new airplane design effort a number of years ago. This display was initially intended to accompany (side-by-side) the PFD, utilizing the altitude tape as the vertical scale for the display. This basic display is shown in Figure **3.4.5-1.** Features of an "Energy Forecast Display" would include: a) aircraft altitude; b) selected glide slope; c) predicted flight path angle (a 10-second trend); d) available flight path angle (under zero acceleration); and e) maximum flight path angle (with go-around thrust).

The primary objective of such an energy forecast display would be to provide an easily interpreted format showing the current, and forecasted, energy state of the aircraft, under the effects of a potential microburst encounter. Basically, the predicted effects of the encounter, in terms of energy height gain or loss, could be plotted on the vertical profile as a function of distance ahead of the aircraft. For example, if the forward-looking system detected a windshear threat out ahead of the A/C, the estimated effects of that threat on the predicted flight path and future available and maximum flight path angles could be depicted on the Energy Management Display. Of course, this same information could be depicted, through appropriate symbology, on a flight path driven PFD. Whether such displays would be useful tools in deciding to abandon an approach or not would be, however, mere speculation without extensive testing of this concept.

3.4.6 Time-Critical Alerting Formats

The function of an "alerting" display element for a time-critical alert, as opposed to a situational awareness element, is to gain the attention of the crew, provide succinct information on the nature of the problem, and some type of guidance or command information on what response is needed. This latter (command) provision would only be applicable to "time-critical" and perhaps "warning" alert levels since only these require an immediate or rapid response by the crew. Of these two alerting levels, it would seem logical that it would be more important to integrate guidance or command information into a time-critical alert format since any time savings in scanning or interpreting the displays would be more important to this more urgent alert level.

One such format is that shown in Figure **3.4.6-1,** which was developed **as** one of several time-critical formats under a previous, unrelated, contract task (Unpublished report). This simplistic graphic was designed to quickly impart the following information:

a) There is a time-critical windshear alert;
b) The aircraft's current position and/or flight path should/can not be maintained;
c) Perform a standard go-around procedure.

The first of these is imparted by the unique elements in this display, the diagonal bars and the "sheared" horizontal bar. The second information segment is imparted by the nature of the alert (time-critical) and the red portion of the display. The command segment is represented by the upwardly pointing arrow, pointing to the green or "safe" area.

In the earlier tests, this format, and other types of formats, were presented either on the PFD **(as** a momentary replacement) or on a dedicated glareshield display. The initial response by pilots (prior to testing) was that this format was too simplistic and cartoonish to be useful as a time-critical alert. However, the results of the tests and of post-test pilot opinion data proved it to be one of the more effective formats. **As** one pilot put it: "This was the only *type* of format that I didn't have to hesitate for a few seconds and ask myself 'Now what is this telling me to do?'". Other similar formats for time-critical alerts such as traffic avoidance, localizer failure on final, and takeoff abort also resulted in as good, or better, performance than those using more traditional formats.

In Figure **3.4.6-2,** the color-filled symbols are dynamic display elements that behaved much **like** normal flight director elements. The red triangular element represents the current aircraft flight path angle, the green "batwings" the commanded (to be safe) flight path, and the amber "baby wings" represented a predicted flight path based upon control inputs. This format seemed to cause some momentary confusion, and thus perhaps could be said to suffer from a lack of familiarity. But since the "arrow" formats were equally unfamiliar, the observed differences probably were due to the "arrow" formats being simpler and more easily interpreted.

In the simulator evaluation of the above formats, the master warning/caution indicator and warning tone in the **757** cab were used to initiate the alert, followed immediately by an alert voice message and presentation of the format either on the PFD or on a dedicated display mounted on the glareshield. It was found that, with this sequence, the pilots tended to be drawn to the upper EICAS display where alerts **are** normally displayed, rather than to the PFD or dedicated display where the relevant command/guidance format could be found. The upshot of this tendency is that perhaps for all time-critical alerts, or alerts that require a maneuver rather than a systems response, a different alerting sequence than is now provided may be desirable. Such a sequence should draw the pilot to the PFD (or wherever the time-critical format is presented) rather than to the alert section of the upper EICAS display.

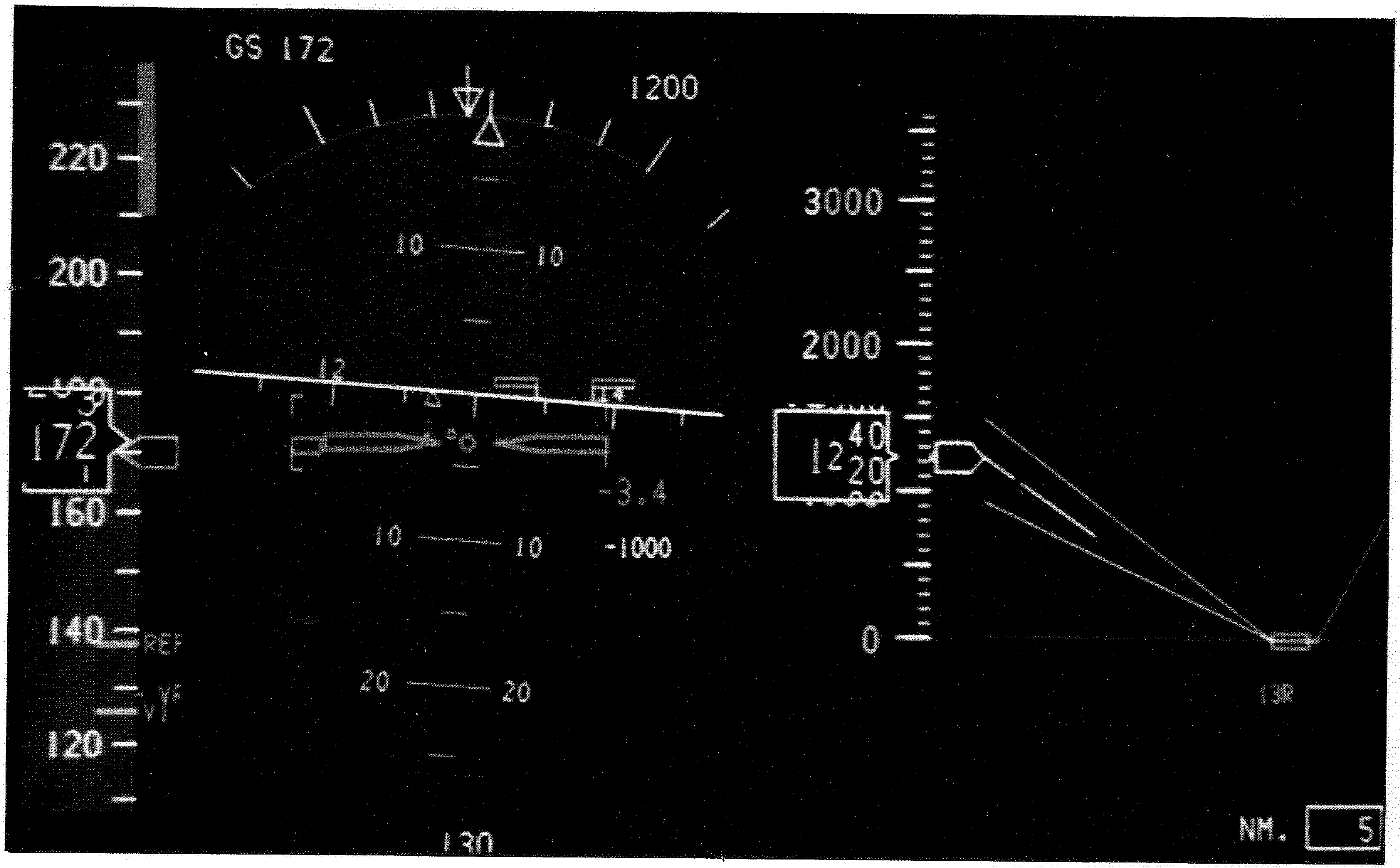

Figure 3.4.5-1 Basic Format of the Vertical Situation Display

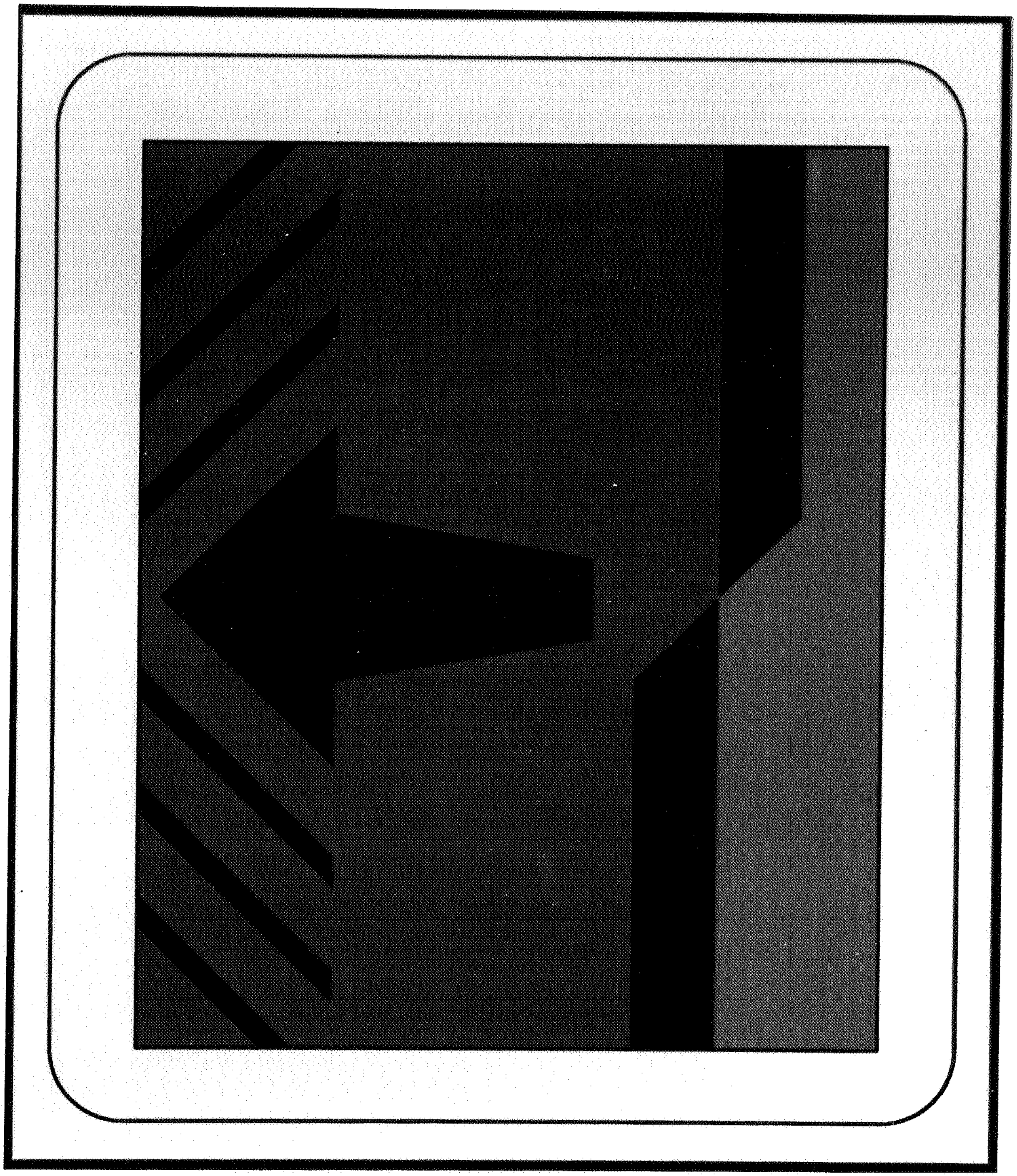

Figure 3.4.6-1 Simplistic Time-Critical Windshear PFD Format

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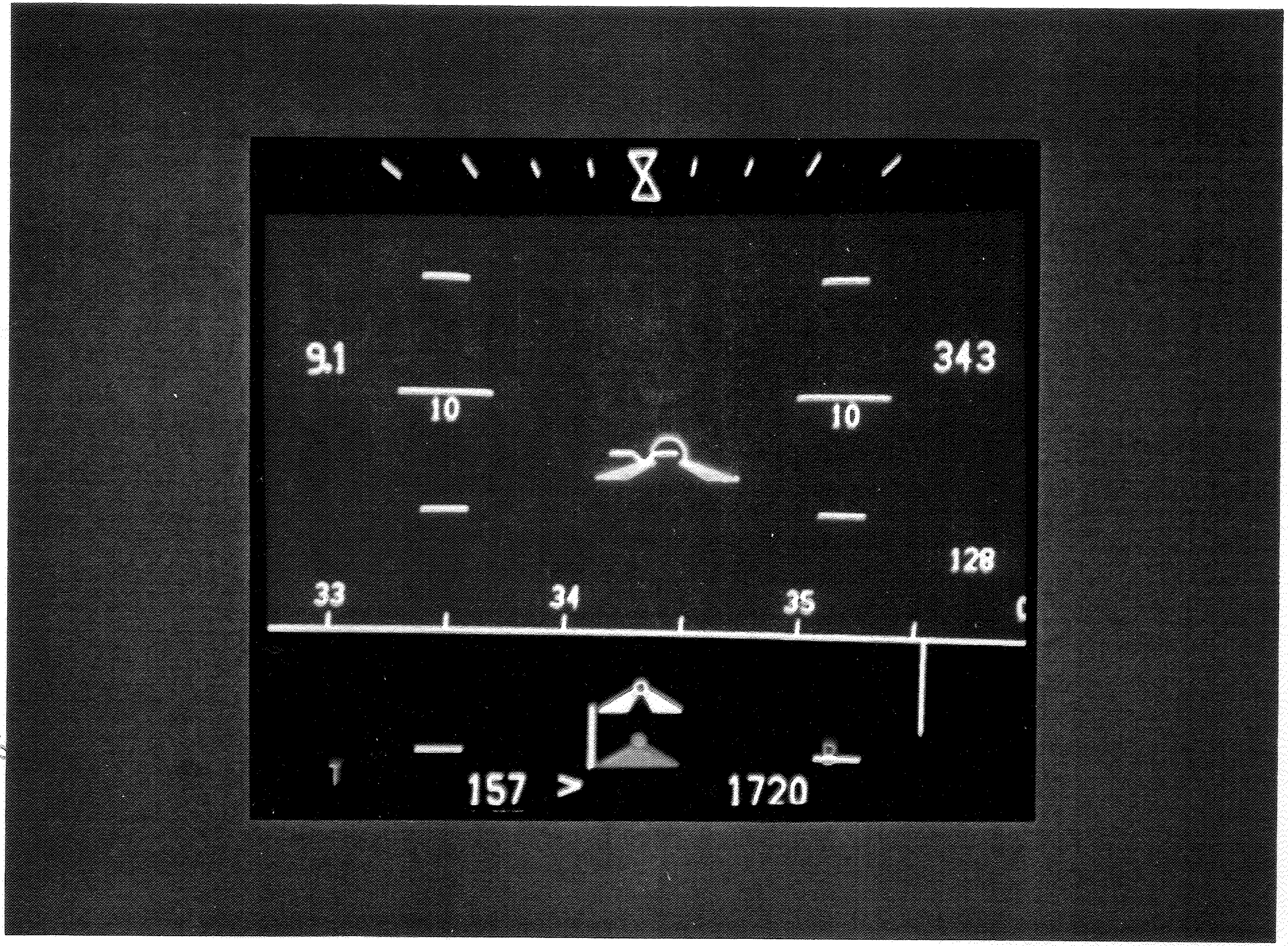

Figure 3.4.6-2 PFD Guidance Elements for Windshear or Other Time-Critical Alerts

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There is no evidence that we know of, or any rationale, for using a different alert sequence than normal for "advisory" and "caution" windshear alert levels (if these are used). Since these do not require rapid responses, it would not seem appropriate to use the PFD for any kind of alerting or command/guidance display.

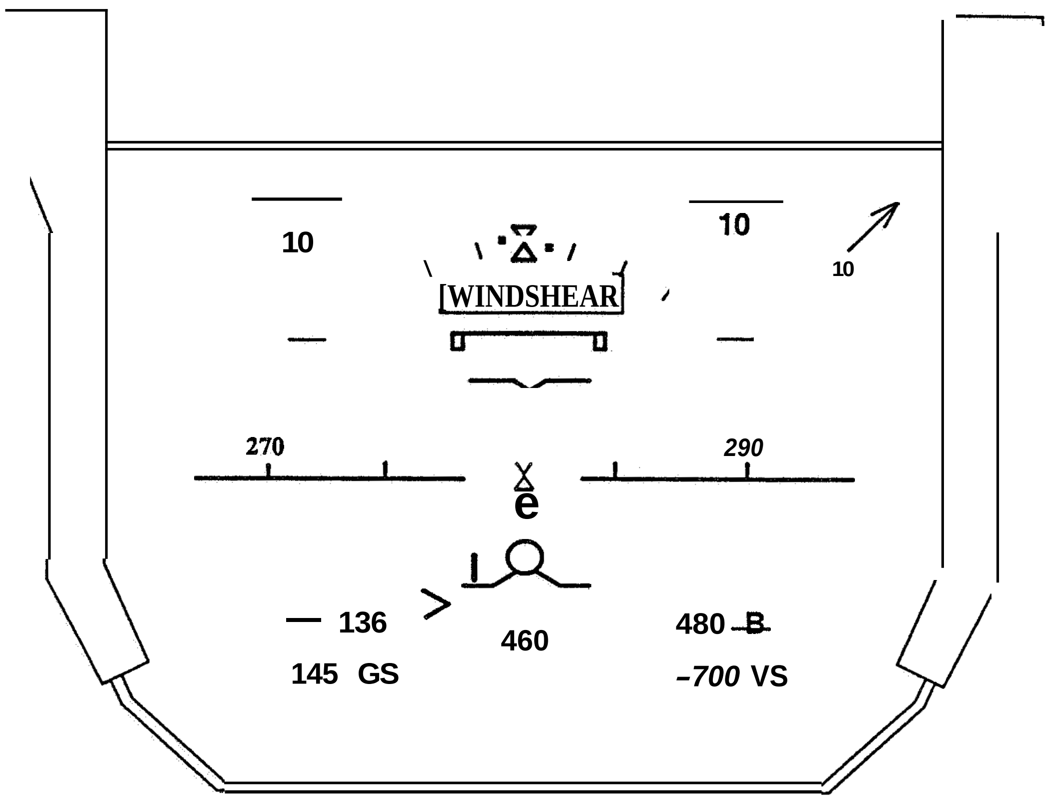
The situation is a little less clear for a "warning" level alert (assuming that the "time-critical" level is also used). This question comes down to primarily one of timing. If the separation between a warning and time-critical alert is chosen at that point at which the normal alerting sequence coupled with a standard (or predefined) go-around or avoidance maneuver can successfully avoid all but minor (non-passenger-disturbing) effects of the windshear, then the PFD probably should not be used for other than time-critical windshear alerting. This question is one which should be resolved by carefully designed simulation studies.

3.4.7 Guidance Requirements

The term "guidance", as it relates to windshear alerts, can have at least two connotations. The first relates to a display format which provides some type of aircraft maneuver command(guidance) for avoidance or escape from microburst effects under a time-critical alert. In the second case, instead of a guidance command on a display, the crew is provided training consisting of procedural guidance for advisory, caution, and perhaps warning level alerts. This type of guidance is normally provided in the alert-based checklists found in the Quick Reference Handbook (QRH). For advisory and caution levels of windshear alerting, this standardized sequence of alerting and checklist procedures is probably adequate. For warning-level alerts(especially time-critical ones), increased levels of training, or perhaps guidance displays, may be needed in working with windshear alerts. Again, as discussed in the previous section, this may also depend upon whether both warning and time-critical levels of alerting are used for windshear.

One display format that has provided both an alerting element and maneuver guidance on a primary flight display is that designed by Flight Dynamics, Inc. (see Figure 3.4.7-1). In this format, used on their Head-Up Display (HUD), the word "WINDSHEAR" appears just under the roll scale as an alerting element. This is consistent with recent implementations at Boeing, except that flight Dynamics provides two alerting levels. The first level is a "Windshear Caution", which is "displayed at approximately 80% of the preset value for full windshear warning". The second level, "Windshear Warning", appears the same as the caution except that a flashing box is displayed around the word "WINDSHEAR".

For guidance, Flight Dynamics provides the "angle of attack limit" bar, similar also to the "pitch limit" bar that is used, by Boeing. But in addition, Flight Dynamics provides a "recovery guidance capability", which utilizes their guidance cue, a normally-open circular symbol, in a special windshear recovery mode. When a windshear warning is triggered, the symbol is shown filled and initially flashes several times (to draw attention). The cue uses a proprietary algorithm to provide escape guidance that offers a



HGS SYMBOLOGY

Figure 3.4.7-1 Flight Dynamics HUD WindshearAlert Fomat

certain recovery profile. This algorithm has been utilized in simulator demonstrations involving a number of "fatal" windshear profiles to illustrate the crew procedures and effectiveness of this **type** of guidance display. Such a guidance cue may be fairly easy to learn, is conceptually and visually simple in design, and(in this case) utilizes existing symbology. It's performance effectiveness is, of course, dependent upon the accuracy and reliability of the algorithm that drives it.

3.5 Crew Alerting and Procedures Flow Chart

To address the issue of crew procedures under forward-look windshear alerting, an effort was made to develop a process flow chart for establishing the criteria for crew alerting, the selection of appropriate alert levels, and development of the associated crew procedures that should follow each alert level.

3.5.1 Objectives of Procedures Development

It is important, in the development of the look-ahead crew interface, to **fust** establish an overall philosophy of alerting in the WS environment that can guide the development of the crew interface to accompany both look-ahead(integrated) systems and the evolution of the reactive system crew interface.

The model taken from the Windshear Training Aid(see Figure 3.5.1- 1) provided basic criteria for guiding crew decisions and procedures in a pre-detection-system environment. The primary operational objectives advanced in this model **are:** a) windshear avoidance; and b) windshear recognition and recovery techniques for inadvertent encounters. The training aid itself provides expanded definitions, descriptions, and procedures for each block in the model, the major goal being to "Reduce windshear accidents and incidents by modifying crew behavior through effective training **and** education". This goal might only be slightly modified for the future look-ahead/reactive(integrated) WS detection systems by adding the provision: "and by providing timely and effective windshear detection systems".

Examination of this model of flight crew actions revealed three primary parts to the model:

1) The precipitating conditions(s) -- in this case: "Any signs of windshear?";

2) A decision on what level of response is required by the crew -- in this case: "Is it safe to continue?"; and

3) The crew procedures appropriate to each alternative outcome of the above decision.

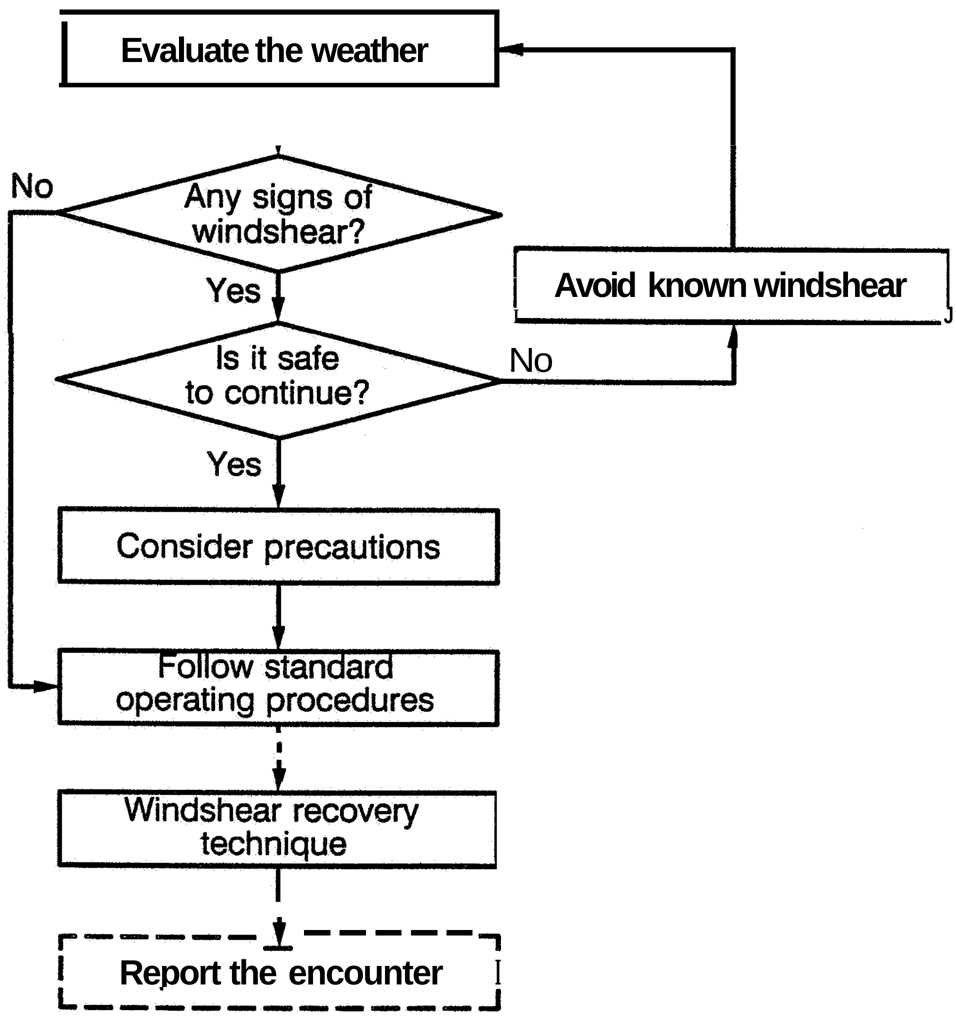


Figure 3.5.1-1 Model of Flightcrew Actions (Source: Windshear Training Aid, FAA, 1987)

After some preliminary development efforts, this same 3-part model structure was selected as the basis for an integrated WS detection "procedures flow chart". The first major question that came up with this procedural structure was: "How many alerting levels (or response decision outcomes) should be used for this integrated alerting flow chart?".

3.5.2 Procedures Model Survey

To get at this, and related questions, a survey was put together and distributed to industry and researchers in the field. For the survey, a "straw horse" outline of the flow chart was developed that could be modified, added to, or replaced with a different structure, by those responding to our request for inputs. It seemed appropriate, therefore, to include in the straw horse all viable levels of alerting that might be selected for inclusion by the respondents. The standardized alerting levels of "Advisory", "Caution", and "Warning" were obvious candidates, although all three of these levels probably would not be appropriate for a final procedural model.

An additional alerting level, that of "Time-Critical Alert" was also considered. In an earlier, unrelated contract effort, this potential level of alerting was studied briefly (as described earlier in this report). This alerting level had been proposed for: a) threats that required an immediate response by the crew (within five seconds); b) a response that is nearly "unconditional" in that the crew always respond immediately to the command unless contrary information is available; and c) threats that require an aircraft maneuver as the primary crew response. After some debate over this potential alerting level, it was decided to include it also in the straw horse flow chart for the survey.

The next step in development of the survey flow chart was to develop "plausible" alerting criteria and crew procedures for each of the four alerting levels. It was desirable to use rather general, or even vague, criteria and procedures since one objective was to keep from proposing a prototype model that was so specific that respondents might evaluate it on an "accept" or *'reject"basis. Rather, the objective was to provide only a "structure" for the flow chart that the respondents would want to "fill in" with their own ideas as to what the criteria and procedures for various alerting levels should be.

The result of this "straw horse" development effort is shown in Figure 3.5.2-1. As indicated, the area that was of primary interest in the survey is enclosed by the dotted line, and consists of the blocks for the alerting criteria, alert levels, and crew procedures. To provide a form for inputs by survey respondents, this section was enlarged, with the criteria and procedures blocks left blank (see Figure 3.5.2-2). The alerting levels were left in to provide reference points, and because it was felt most respondents could selectively use these levels by just crossing out the ones they felt should not be included in the flow chart.

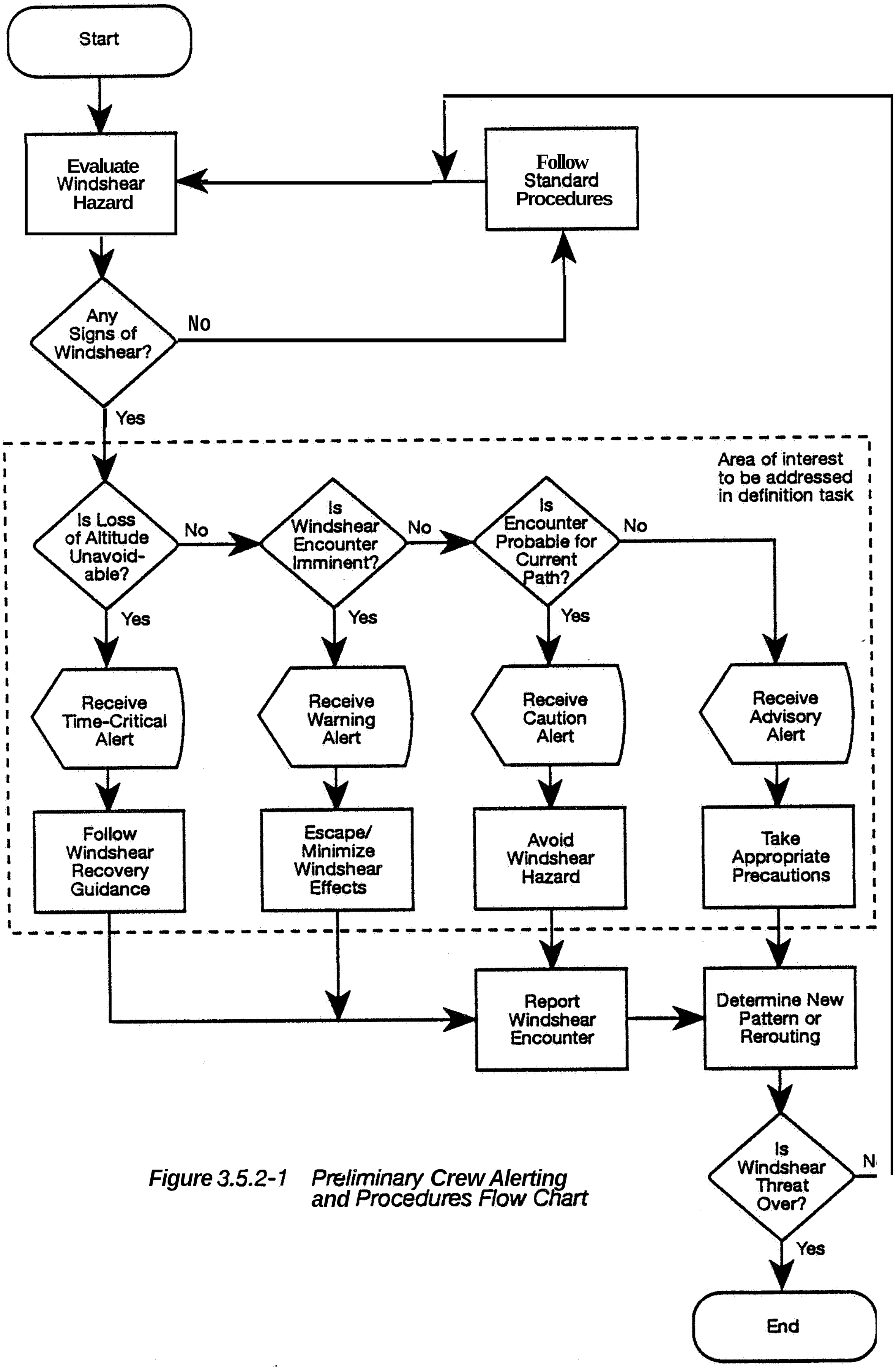


Figure 3.5.2-1 Preliminary Crew Alerting and Procedures Flow Chart

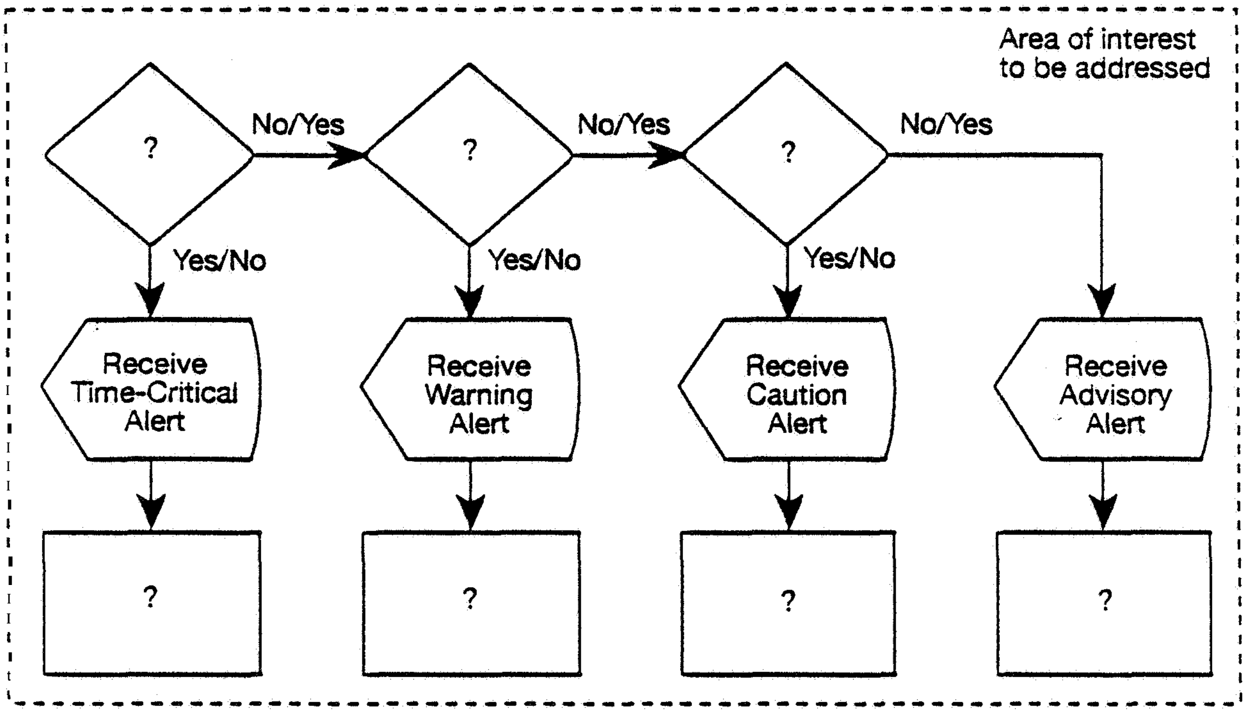


Figure **3.5.2-2** ***Area of Interest in Crew Alerting and Procedures Survey***

In addition to these forms, a sheet was included for the respondents to fill in descriptions of the alerting criteria and crew procedures. Finally, background material, including the purpose of the survey, the Training Aid model, **etc.,** were included in the survey package to give the respondents the basic information needed to complete the survey. Once completed and reviewed, the survey was distributed to about **40** individuals throughout industry, the airlines, FAA/NASA, and the Boeing Company (see Appendix VIII for a copy of the survey).

3.5.3 Preliminary Results of the Survey

The responses that came in indicated that there is indeed a variety of opinions on aspects such **as** what alerting levels should be used and on the criteria and crew procedures that should accompany these levels. An initial review of these early responses found that the four levels of alerting were all used by one or another of the respondents, and some respondents used all four in their proposed flow chart. Summaries of a number of the responses received are described in the following paragraphs.

Respondent "A" - proposed the flow chart model shown in Figure 3.5.3-1. Under this scheme, all four alerting levels were used, under a range of conditions from "Any sign of windshear?" to **"Has** windshear been penetrated?". Perhaps the criteria most difficult to determine under this scheme would be that for differentiating a "caution" from a "warning" condition: "Can windshear be avoided?". For associated procedures, respondent A suggested straightforward crew actions. The one item to note here would be that under a time-critical alert, a "wings level" recovery [maneuver] was recommended.

In Figure **3.5.3-2,** more detail was provided by respondent A on these maneuvers, along with recommendations for "g"-based thresholds for the various alerting levels of both reactive and look-ahead systems. Note that this respondent also would like to specify some "distance to hazard' criteria for each alert level, but concludes that these are currently undetermined.

Respondent "B" - also submitted a complete flow chart, but incorporating two levels of alerting: advisory and time-critical (see Figure **3.5.3-3).** The focus **of** this respondent's flow chart is on crew situational awareness, using the advisory alert to draw the crew's attention to the display of projected windshear effects on the planned flight path and depicting also the potential flight path available. For an advisory alert, a windshear threat (F-factor) greater than threshold that is detected by a forward-looking system "exists over an extent of a kilometer or more and is greater than the (TBD) seconds flying time away that would trigger a time-critical alert (but less than **2** or **3** minutes away)". The advisory alert could also be triggered by a windshear threat above threshold that is detected anywhere in the region under conditions where the windshear display mode is not selected/enabled.

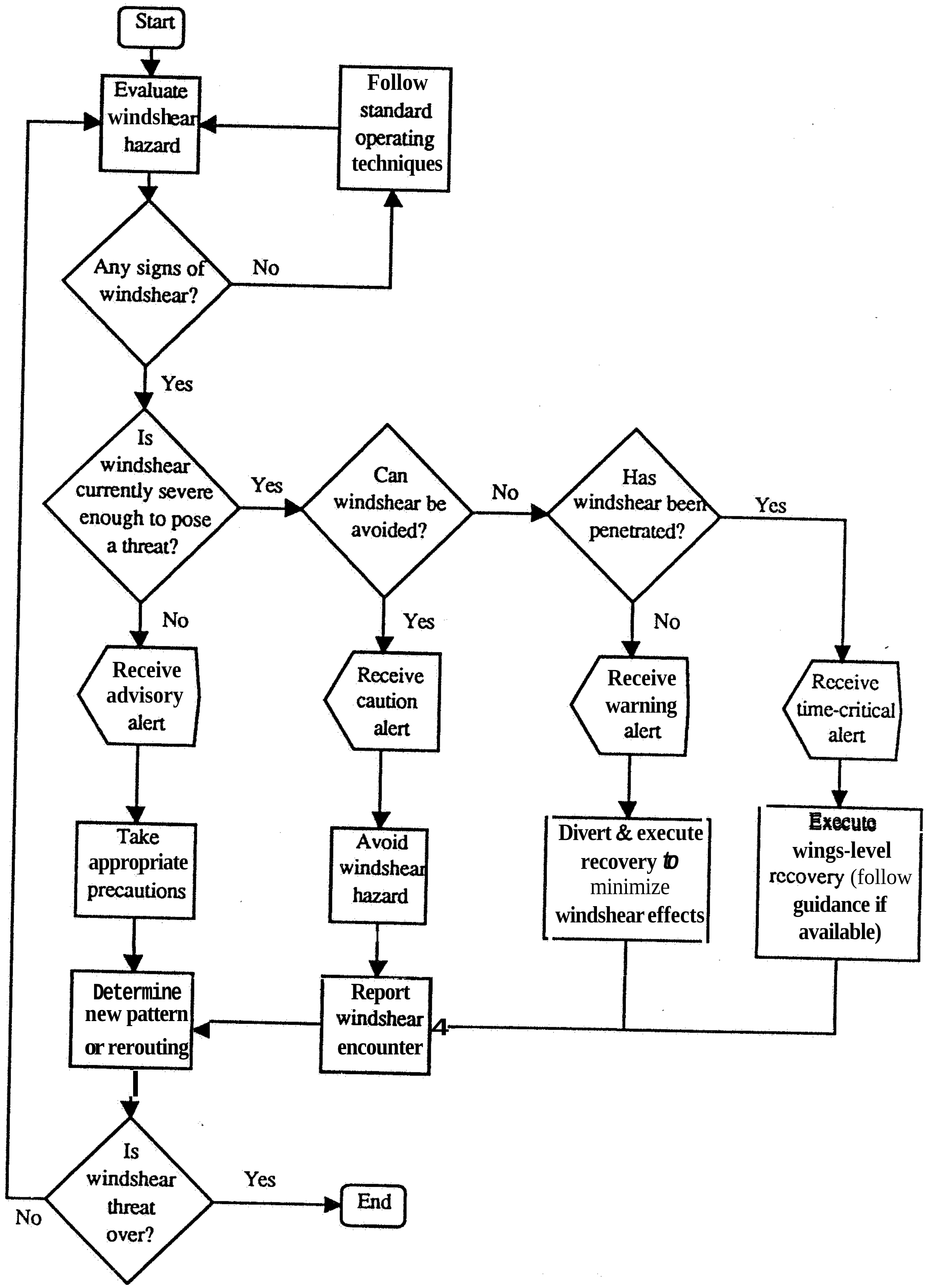


Figure 3.5.3-1 Suggested Flow Chart from Respondent "A" for Windshear Alerting and Crew ***Procedures***

Alert Level	"Reactive" System Threshold	"Look-ahead" System Threshold	Distance to Hazard
Time-critical	≥ 0.12	≥ 0.12	0
Warning	(not applicable)	≥ 0.12	0 < ≤ TBD (insufficient to avoid)
Caution	(not applicable)	≥ 0.12	> TBD (sufficient to avoid)
Advisory	(not applicable)	< 0.12	Any

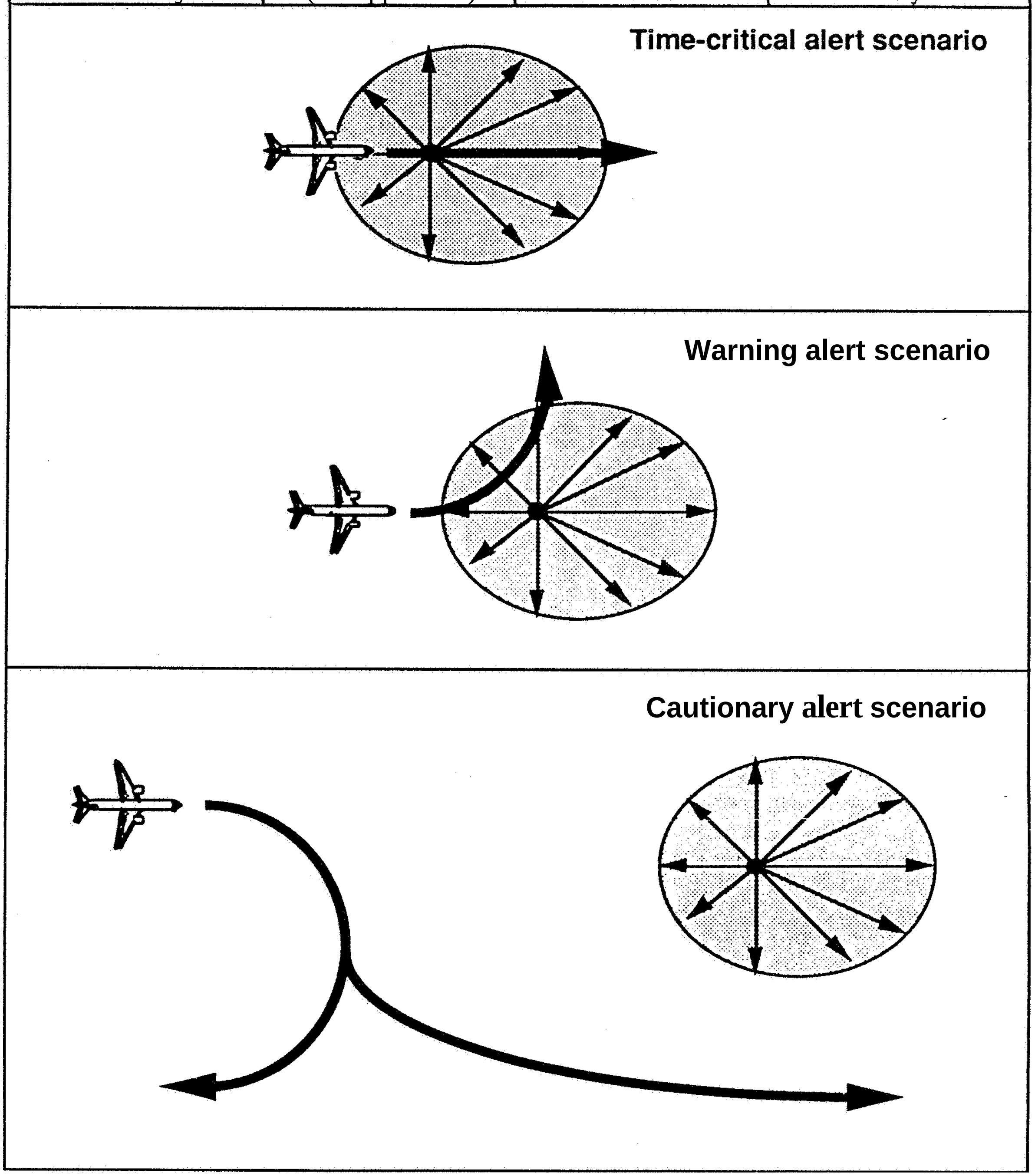


Figure 3.5.3-2 Respondent "A" Recommendations for Alerting Thresholds and Flight Maneuvers

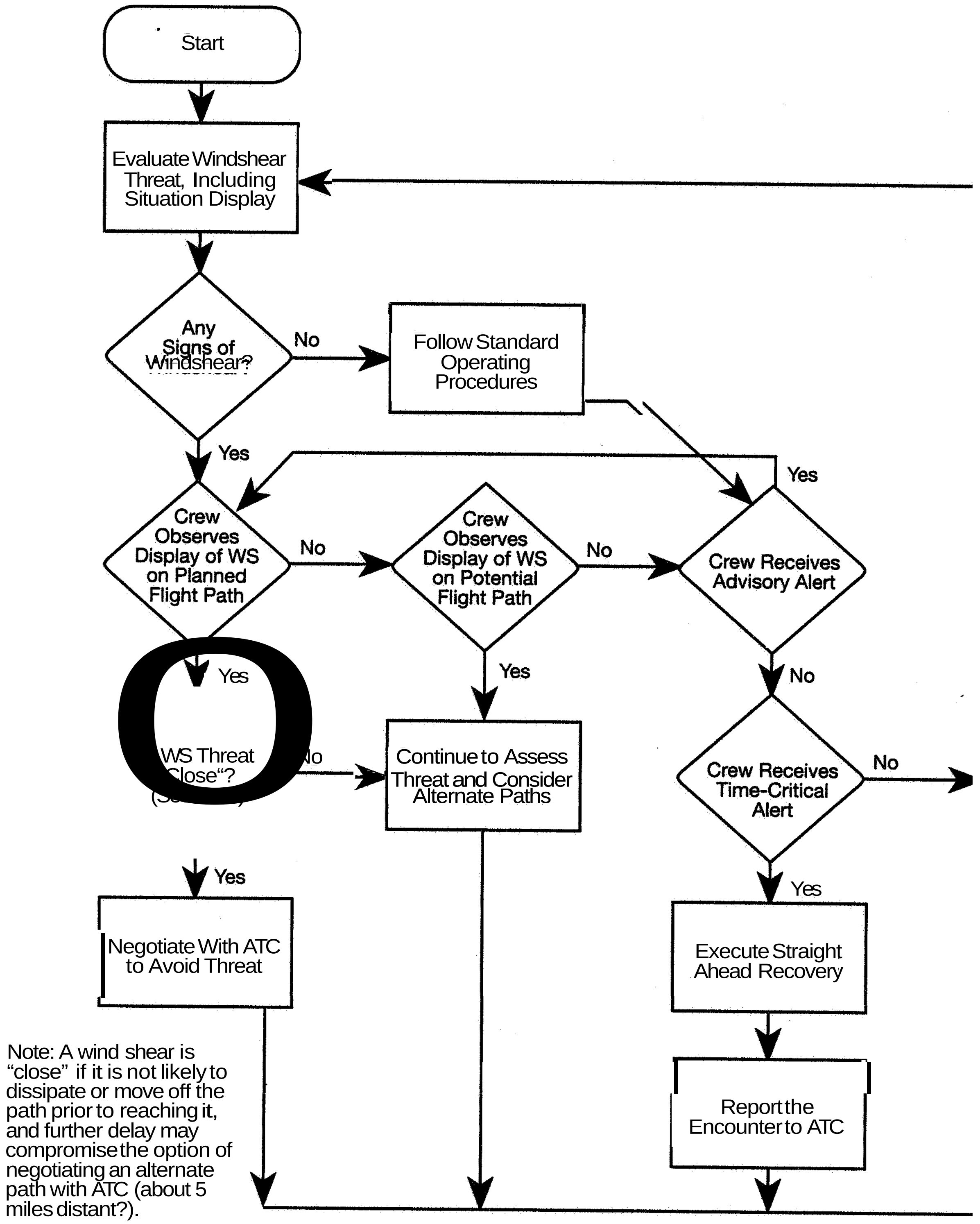


Figure 3.5.3-3 Respondent "B" Recommendations for Crew Action Flow Chart

The time-critical alert would be triggered by a threat(F-factor) above threshold that "exists over an extent of a kilometer or more and is no more than (TBD) seconds flying time away(probably 60-90 seconds). This alert would probably be inhibited during part or **all** of the takeoff roll.

Respondent "C" - assumed **an** "integrated sensor" approach, with two or more forward-looking sensors, combined with a reactive system component. It was suggested that multiple forward-looking sensors(e.g., one radar and one IR) could serve to reduce false alarms and increase detection (alerting) sensitivity.

This respondent associated the various alerting levels with the immediacy and probability of the threat, and therefore with the amount of time(for different situations) within which the crew would be required to react(see Figure **3.5.3-4).** The recommended reactions ranged from "windshear precaution" to "windshear recovery" procedures.

Respondent "D" - developed criteria for each of the four alerting levels(see Figure **3.5.3-5)** but, like the fist respondent, based at least some of the distinction between them on the probability of the threat. While the time-critical alert was recognized as requiring an immediate, though not necessarily "unconditional" response, the appropriate response time for warning or caution alerts was felt to be in the range of 15 to **40** seconds. The other factor this respondent used to differentiate the alert levels was the reliability of the alerting prediction, with a 95% reliability required for time-critical and warning alerts, and 70% reliability recommended for caution and advisory alerts.

This respondent recommended an optimum energy windshear recovery maneuver down to **300** ft AGL in response to a time-critical alert. Below **300** ft. AGL, it was felt that energy should be traded for altitude. It was also felt that guidance would be required in the case of a time-critical alert. For other alert levels, standard procedures, with pilot options, were recommended.

Respondent "E" - interpreted the survey to be directed only at a predictive system and therefore completed the flow chart for only those alert levels thought to be applicable to a look-ahead system, specifically the caution and advisory alerts(see Figure **3.5.3-6).** However, comments submitted generally supported the four levels of alerting for the flight deck. It was pointed out that the time-critical alert level was not universally accepted and not currently(at that time) used on existing flight decks. It was emphasized that the "unconditional" aspect suggested in the survey description for time-critical alerts was not, in the respondent's opinion, an acceptable provision. It was recommended that this category be defined as "An operational condition which requires immediate pilot awareness and immediate corrective or compensatory action to maintain safe flight".

It is worth noting that the **term** "unconditional" could be interpreted in more than one way. For this respondent, it seemed to imply that a certain, pre-determined response would always be immediately required. However, it could also mean, as was the intent, simply that a response(of some kind) was immediately required, without further evaluation of "conditionals" by the flight crew. The purpose behind this type of

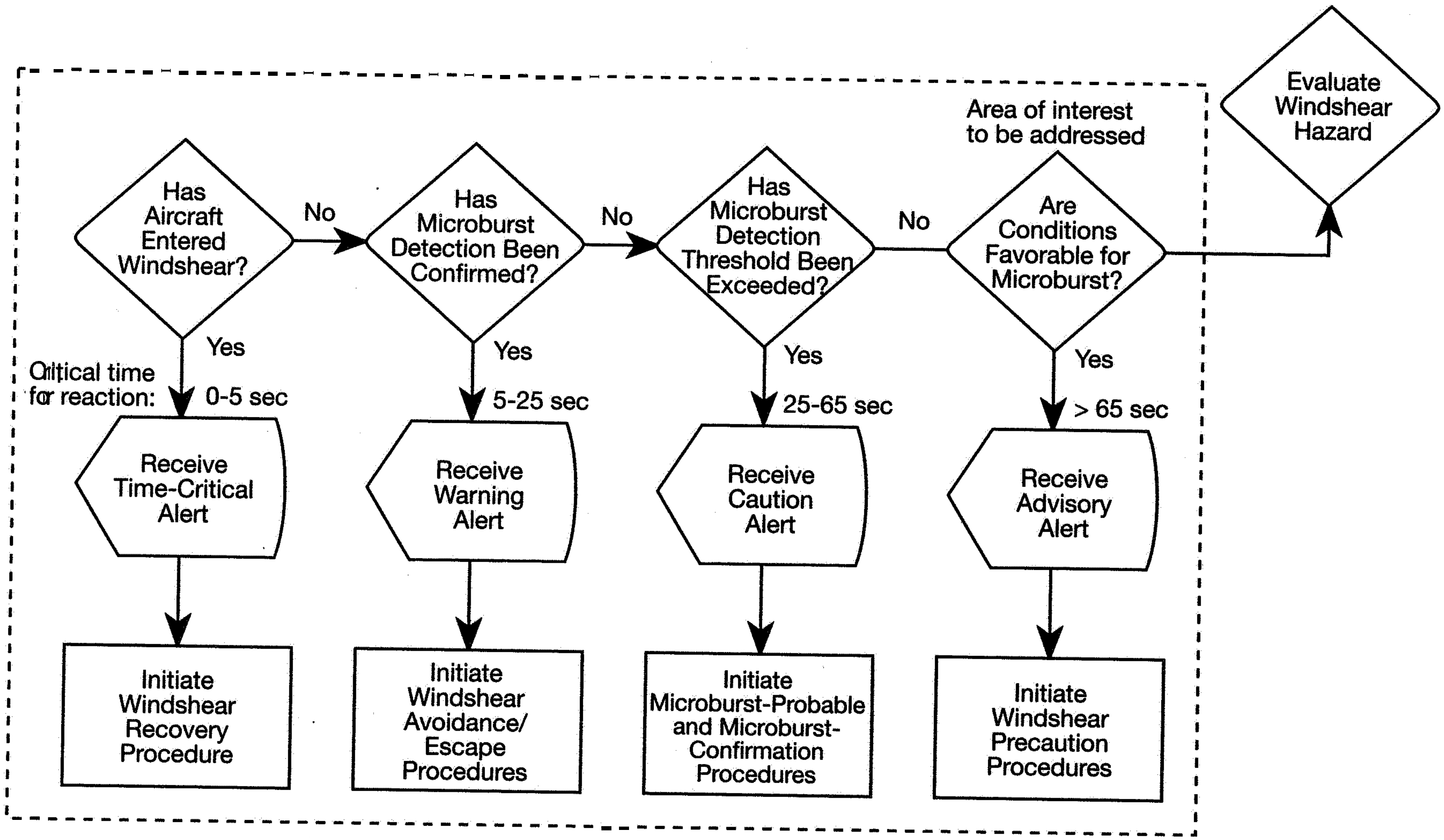


Figure 3.5.3-4 Respondent "C" Recommendations for Crew Alerting and Procedures Flow Chart

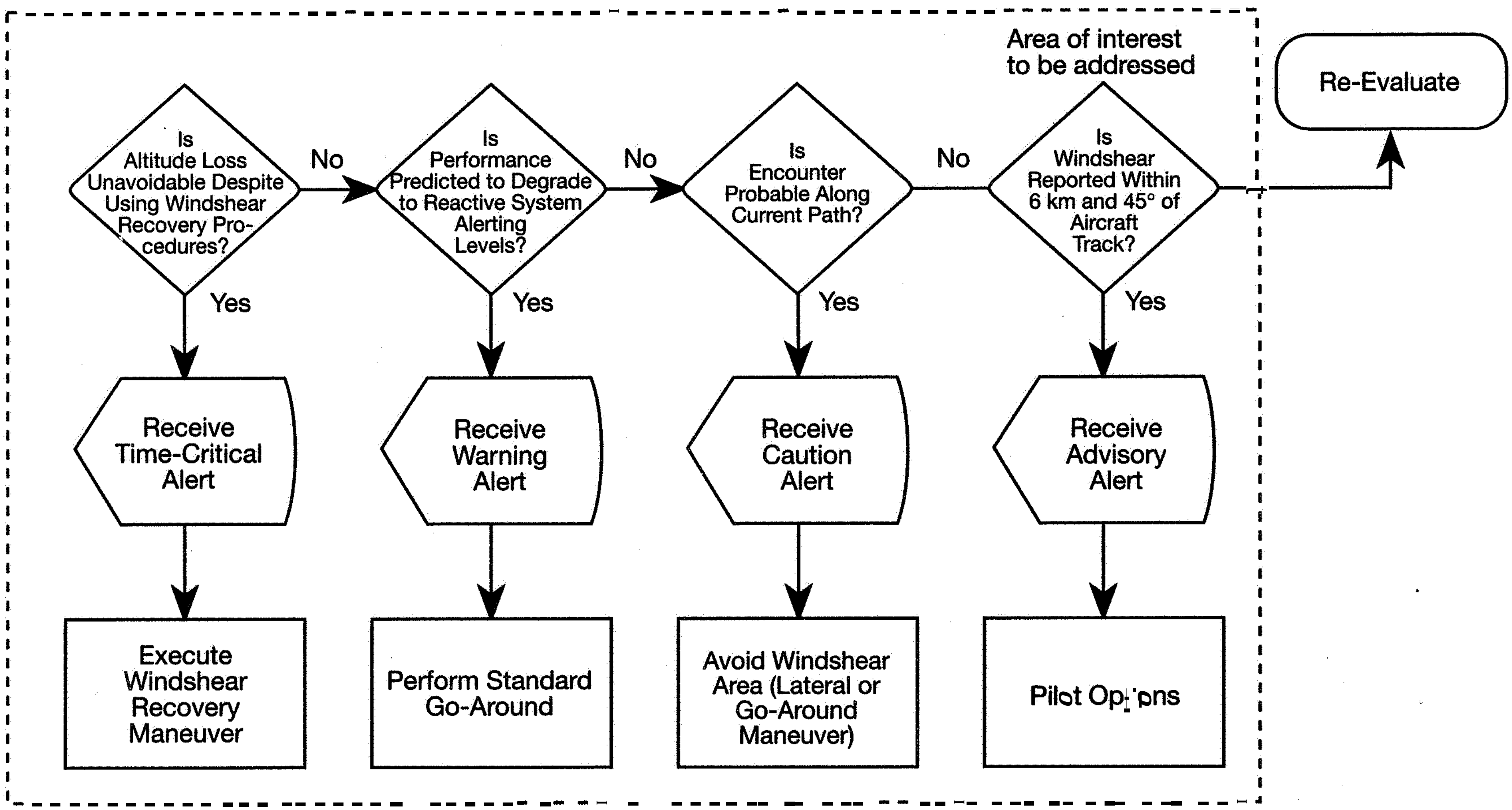


Figure 3.5.3-5 Respondent "D" Recommendations for Crew Alerting and Procedures Flow Chart

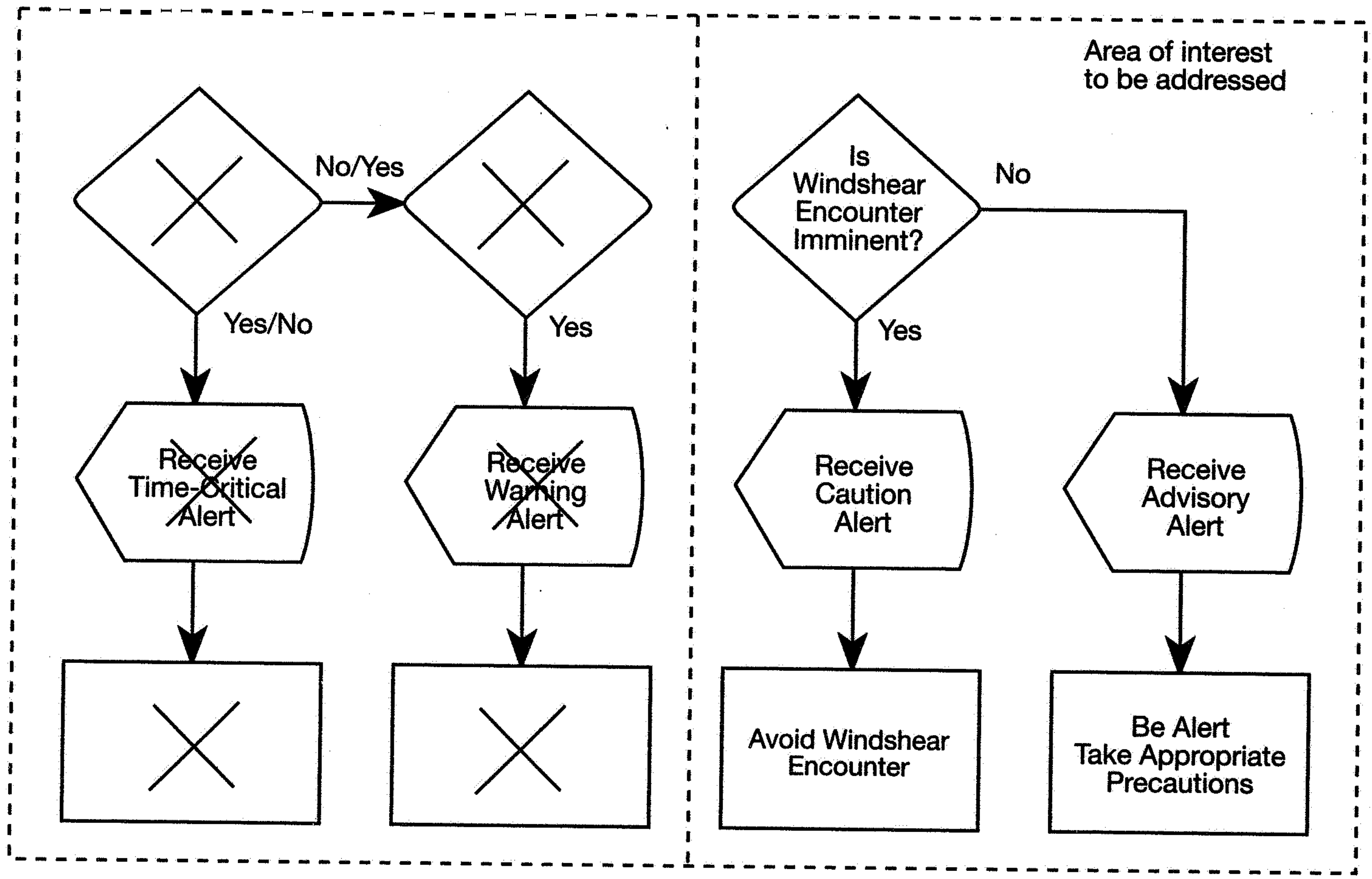


Figure 3.5.3-6 Respondent "E" Recommendations for Crew Alerting and Procedures Flow Chart

unconditional response is to allow for an immediate crew action, without the time delay caused by evaluation of other qualifying conditions. However, the response itself, might vary (in type but not in immediacy) depending upon conditions, and in this way could also be thought of as a "conditional" response. Obviously, this is a sensitive aspect in the consideration of a time-critical alerting level, and one which warrants further study and debate.

Obviously there is a variety of opinion on what the alerting components and crew procedures should be for an integrated windshear detection system. Hopefully these varying viewpoints will stimulate the discussion, debate, research, and development needed to move toward an effective and efficient system -- one which will be accepted and successfully implemented throughout the industry and the user community.

4.0 CONCLUSIONS & RECOMMENDATIONS

4.1 Conclusions

4.1.1 Issues Identification

A literature review and survey of subject-area experts both supported a position that the crew interface issues involving advanced windshear systems should be addressed early on. The survey identified the more critical issues of the flight management area that should be addressed in the airborne windshear detection program. The top five issues identified in the survey were: 1) missed alert acceptability; **2)** avoid distance in front of the **aircraft; 3)** false alert acceptability; **4)** nuisance rate acceptability; and ***5)*** the proper crew procedures. All issues were organized as part of an easily accessible database of crew information issues and methods of solution for industry to use.

4.1.2 Alerting System Design Considerations

Crew use of displays and windshear information will be shaped by the system objectives, philosophy, and guidelines for usage. The task of determining the system objectives and guidelines will require industry, regulatory agencies, and user involvement. One goal is the determination of crew response capabilities, guidance capabilities and requirements, ground and airborne information capabilities, and sensor limitations.

Data and pilot opinions gathered indicate that the information provided to the pilot by advanced windshear detection systems should be structured to provide time to avoid the hazard altogether or warn appropriately and command maneuvers to successfully deal with or avoid the hazardous region. Integration of reactive and look-ahead systems must be accomplished at the alerting level in order to command the proper pilot response. Since alerting may occur at a number of different warning levels, the appropriate associated display issues must also be addressed. These alerting and/or situation displays should be designed to make flight crews appropriately aware of the hazard and to command the appropriate procedure to be followed. Effective and efficient crew procedures should be considered in all stages of the crew interface development process.

4.1.3 Alert Timing Simulation

Evaluations of crew performance using advanced windshear systems should be developed jointly as work progresses into the crew interface areas. These areas of crew response to look-ahead alerting, display development, and the range of alerting options can help form the underlying structure for future efforts.

Boeing conducted a look-ahead windshear detection warning simulation to determine pilot reaction and performance given various timings of a look-ahead alert, using the wind model developed by NASA. Since all the new technologies are using this model, NASA is interested in pilot performance and reaction to the model. Boeing was one of the first to put this model into an existing simulator and five Boeing pilots were used to accomplish a total of **110** approaches into this windshear model.

Conclusions from the results of the simulation were: 1) pilots considered the model an intense windshear but lacking turbulence and roll transients; **2)** in 90% of the cases, the look-ahead warning given 32 seconds prior to the core **(11** seconds prior to the reactive alert) was considered to be too late to be considered an effective look-ahead alert mechanism; 3) in 90% of the cases, the look-ahead warning given 57 seconds prior to the core (36 seconds prior to the reactive system) was considered to be given too early and that a look-ahead system should spend more time evaluating the phenomenon than giving time-critical alerts that early; 4) the average warning time considered to be appropriate for a look ahead warning was **44** seconds prior to the core (23 seconds prior to the reactive alert); 5) the standard go-around was considered to be most appropriate for time-critical warning alerts given at the average look-ahead warning time; and 6) escape maneuvers did not require lateral turns.

While the S-7 committee's ARP on windshear alerting has been instrumental in focusing attention on the establishment of system definitions and parameters for the windshear detection arena, there remains considerable difference in opinion as to the criteria for alerting and crew procedures under various windshear conditions. The initial development effort on defining a process model for alerting criteria and levels of urgency, and for associated crew procedures, has been fruitful in generating discussion and ideas of how the complex situation of look-ahead windshear detection and alerting should be dealt with.

4.1.4 Windshear Display Alternatives

Displays concepts were developed and/or evaluated for three types of information requirements: a) alerting the crew; b) providing guidance to avoid or escape the windshear; and c) status displays to provide windshear situational awareness to the crew in the look-ahead environment.

The more promising icons for microburst characterization can provide a tool for the assessment of pilot decision-making and alert timing in a variety of threat level, look-ahead detection, situations. A 3-dimensional icon for use on a perspective PFD display may provide the ability to "see" the microburst out ahead of the aircraft, but the utility of such a presentation awaits simulation evaluation.

Appropriate format designs for alerting the crew, in the look-ahead environment, depend upon what alerting level is being activated. Just which alerting levels are needed for an integrated system appears to become less certain as discussion and consideration of this

issue continues. In this regard, the alerting and procedures model can help to focus considerations on the issues involved in following standardized alerting system definitions and recommendations. Again, the four levels studied here are not commonly used on current airplanes but were useful in exploring possible windshear alerting levels.

Some windshear situations however, may require more specific guidance information. Again, the PFD is the logical display for such guidance information, which could use either standard flight director elements or perhaps additional or modified elements to provide limits, trends, or command cues that are unique to the windshear environment.

For windshear status information, display formats were developed for: 1) depicting microburst icons on a nav/map display; 2) depicting a 3-dimensional microburst icon on a perspective primary flight display (PFD); and 3) depicting the predicted effects of the anticipated windshear on the energy height and performance capability of the aircraft, shown on the lower EICAS display.

4.1.5 Alerting Design Considerations

The evaluation of alerting requirements focused on the standardized alerting and procedures scheme now used by most manufacturers. This concept is based upon three levels of alerting: a) advisory, b) caution, and c) warning. Over a dozen years of research has led to very specific recommendations for all of the crew interface aspects associated with these alerting levels (Ref.8). Whether all three of these alerting levels will be appropriate to integrated look-ahead/reactive windshear detection systems is a basic question to be resolved by a combination of analytical and simulation studies.

In addition to these three alerting levels, a fourth level was considered as a possible addition to the WS alerting scheme. This would be a "time-critical" alert, defined here as an alert that requires an immediate aircraft maneuver as the primary crew response. Several potential formats for such an alert have been looked at in previous, unrelated, studies. Simple, graphic formats presented on the PFD appeared to offer the most promise to satisfy the dual requirements of alerting the crew and providing some basic form of guidance.

4.1.6 Crew Alerting & Procedures Model

An important determinant in the development or selection of crew interface display formats is the establishment of crew information and performance requirements. These in turn are dependent upon the alerting philosophy followed and the specific operational procedures established for each possible windshear situation. In order to develop an alerting and crew procedures approach that would result in the most acceptable and useable display concept, an effort was undertaken to begin formulation of a "Crew Alerting and Procedures Model" for the integrated forward-looking/reactive windshear detection environment.

The initial development effort started with the familiar "Model of Flight Crew Actions" found in the FAA's Windshear Training Aid. From this model, a "straw horse" Crew Alerting and Procedures Flow Chart was developed that included the basic three elements of: a) alerting criteria, b) alerting levels, and c) crew procedures. After some preliminary discussions, four levels of alerting were selected as possible viable levels of windshear alerting in the integrated look-ahead/reactive detection environment.

The survey instrument that was developed to gather specific inputs from other researchers in the area, from cognizant pilots, and from industry representatives was distributed to over 40 individuals or organizations. The responses indicated that there is a wide diversity of opinion on which alerting levels, which criteria, and which crew procedures should be used for integrated windshear detection systems. The responses could be used to develop a more sophisticated model for the future operational environment. This model hopefully, then, point to the alerting and procedural aspects that will need to be further developed through simulation and flight testing.

4.2 Recommendations

The following recommendations are made for future research activities to address remaining crew-interface issues.

A simulation should be conducted that studies the categorization and timing of alerts in an environment where look-ahead situational awareness of the windshear microburst is provided. This study would involve pilots' real-time determination of appropriate alerting points for different windshear and alerting levels, utilizing the look-ahead situational information. The shear model to be used should be varied in shear rate, strength, location, etc. so that a relationship can be established between warning time, alert level, shear characteristics, and the expected crew response/performance. This simulation would address the issues of alerting categorization and criteria, determination of alerting as a function of distance and windshear threat level, and look-ahead response time requirements.

The second major task would involve the use of piloted simulator sessions using the NASA wind model. This simulation effort would expand on the conditions used in the first study, to include takeoff situations, different aircraft, alerting, and crew procedure options. Pilot performance would be measured, and questionnaire data gathered, to determine appropriate alerting and guidance procedures for various configurations (intensities and locations) of the NASA windshear model. The focus of this simulation should be on detection situations where alerting, guidance, and procedural options are available and can be compared. This simulation would address the issues of guidelines for guidance commands, implementation of alerting criteria and procedures, and the verification of alerting as a function of threat level and distance.

Attempts to establish alert timing requirements from simulation tests can be hindered by the crew's expectation, and anticipation, of the alert. It is recommended that look-ahead

windshear simulations be conducted in more realistic environments in order to obtain more accurate response time measures under a variety of look-ahead windshear alerting conditions. This data would help substantiate earlier analyses of the minimum warning time required for alerting.

A third task would be to develop and evaluate possible alerting display format candidates for look-ahead systems. These candidate formats should be based upon results of prior development/evaluation efforts. Situations should be developed to depict various windshear conditions as well as nuisance and false alert situations. Pilots should be used to evaluate the displays and their use for situational awareness or for time-critical alerting. Promising candidates could be selected and the software developed for the transfer of those displays to the simulator. This task would focus on many of the interface issues identified earlier, including nuisance rate acceptability, effects of lateral avoidance, weather radar overlays and various other display and crew interface issues.

Work should continue on development of a Crew Alerting and Procedures Model. Results of the survey should be followed up with at least one working-group meeting between the various interested parties (users, researchers, sponsoring agencies, system vendors, airframe manufacturers, etc.) to iron out as many differences of opinion as possible. As research findings become available, they should be used to help resolve remaining issues in the model. This effort would provide one basis for the development of functional and design guidelines for integrated windshear detection systems.

Future research activities should include the integration of time-critical alerting, reactive alerting, and longer range informational displays in the research simulator in such a manner that it can easily be transferred to an aircraft testbed. Future activity may also be needed in the area of sensor fusion at the crew interface level, to deal not only with the interface between airborne systems, but also on how ground information may be processed on airborne platforms. This area will require that data-link, and perhaps expert systems techniques, be applied to the windshear problem.

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APPENDICES

Appendix I

Crew Information Issues Survey

A Survey to Help Determine the Priority of Research on Crew Information Issues Involving Advanced Windshear Detection Equipment

I. Introduction:

This survey is part of a program to determine the focus and priority of research efforts involving advanced windshear detection. The flight crew has many information sources available to cope with dangerous windshear situations. These information sources are expanding with the probability that look-ahead sensors may be added to present windshear detection capabilities. Understanding what information the crew needs becomes increasingly important as flight crews seek, with the aid of advanced sensors, to avoid entering hazardous windshear conditions. The introduction of look-ahead sensors as a natural next step in windshear detection reveals crew information issues that need to be resolved. We must determine how much data and information the crew needs and the integrated presentation concepts, which consider pilot workload, that should be adopted. The resolution of these issues will assist in the development and implementation of improved windshear detection equipment.

11. Purpose:

This survey document is a compilation of crew information issues to obtain opinions relating to hazardous windshear avoidance. The results of this survey will be used to determine the priority and focus of future research involving the crew interface with advanced windshear detection systems. It is intended that this document eventually will be a living report of the crew information issues involving advanced windshear detection systems. It will be updated to reflect research activities as they effect the issues.

III. Objectives:

The objectives of this issues document are to help mature future windshear systems by:

* Documenting identified crew information issues associated with advanced windshear detection systems;

* To provide requirements for research activities to address the issues raised;

* To sample opinions and provide a sampling document for identifying issues of human engineering concern dealing with windshear detection systems.

IV. Scope:

The scope of this survey document is limited to advanced windshear detection system crew interface and information issues, problems, and requirements for implementation,

Identified issues will be addressed by NASA, FAA, and Boeing Flight Deck Research for possible research funding and issue resolution. Please feel free to add any additional issues you feel are important and the appropriate rating that issue should receive. Return the completed crew information issues survey to:

Dave Carbaugh
Flight Deck Research
Boeing Commercial Airplane Company
P.O. Box 3707, MS 66-25
Seattle, Washington 98124-2207
Phone: 206-237-7286

Please return your survey by 1 December 1987 and indicate if you would like to receive a copy of the results.

Your time and thoughtful responses to this survey will be greatly appreciated.

Survey Definitions and Limitations

Definition of issue ratings:

On the next page starts a list of crew information issues involving advanced windshear detection systems. This list is by no means complete. Please rate each of the issues into the following four categories.

CRITICAL

* Issue resolution required prior to industry-wide implementation of look-ahead advanced windshear detection systems

SERIOUS

* Should be resolved prior to industry-wide implementation of look-ahead advanced windshear detection systems

DESIRABLE

* A resolution of an issue could be expected to improve the physical and/or operational man-machine interface

NO OPINION

* Issue not applicable or unclear

The limitations of this survey are:

* The focus of this survey is on the incorporation of forward-look technology on airborne platforms (although ground information will form a factor in the crew decision making process, our focus is on airborne systems);
* Issues should be involved with the man-machine interface (from the instrument panel to the pilots and back);
* Issues should not directly require FAA procedural changes;
* Issues should not be sensor specific;
* Present day reactive sensors are considered to be non throw-away technology that would be incorporated as part of any advanced windshear system.

Crew Information Issue List

Name ______________________

Organization ________________

Ratings - C=Critical
D=Desirable
S=Serious
N=No Opinion

In the area of displays.....

1. What is the benefit to crews to have look-ahead capable windshear systems identify non-critical shears (those shears with thresholds below present alerting levels)?

2. Would crews benefit from actual or derived look-ahead wind velocities being actually displayed to the flight crew?

3. How far in front of the aircraft does the crew need to receive windshear information to make avoidance decisions?

4. How far displaced from the centerline of the flight path do pilots need to see windshear information for safe takeoff and approach?

5. At what points, given a look-ahead sensor detecting hazardous windshear during an approach or takeoff, would crews benefit from guidance commands for conducting escape maneuvers?

6. What would be the benefits to crews to have forward-look windshear information displayed in a three-dimensional manner?

7. Can windshear look-ahead warnings and information be integrated into present day electronic and conventional flight deck displays?

8. What would be the benefits to crews to have microburst movement information displayed using look-ahead windshear systems?

Name ________________________

Organization___________________

9. What would be the benefits to crews to have look-ahead raw wind information(as compared to relative wind/energy information) displayed by forward-look devices?

In the area of controls......

10. What benefits can be gained by crews by being able to control the look-ahead field of view for takeoff or approach to avoid hazardous windshear?

11. What are the benefits to crews to have crew selectable look-ahead parameters(field of view, range of view, look-down angle,etc)?

12. What are the optimal crew operating procedures for use of look-ahead windshear information?

13. To what extent will pilot control of windshear system parameters make the look-ahead windshear system more acceptable to flight crews?In the area of alerting and crew interface...

14. What benefits can be gained by crews if look-ahead capable windshear systems alert on energy increasing shears?

15. What benefits do crews gain from being aware of total magnitude wind changes even if the rate of change of the shear is not dangerous?

16. What windshear system nuisance alert rate is acceptable to crews using look-ahead capable windshear systems?

("Nuisance" means shear exists but is not a factor to the crew because of location of shear or changing intensity of shear. "Acceptable" means crews react to the alert in a safe manner.)

17. What look-ahead windshear system missed (system fails to detect shear) alert rate is acceptable to crews?

Name ______________________

Organization ____________________

18. What look-ahead capable windshear system false (system error - shear does not exist) alert rate is acceptable to crews?

19. Do crews react to look-ahead windshear warning alerts in an executive manner or in an advisory manner? ("executive" means crews are required to follow guidance unless they have reason to believe that they shouldn't. "Advisory" means crews follow guidance only if they have some other reason to believe that they should.)

20. What benefits would crews have if reactive windshear systems alerting thresholds are rescheduled by **look-**ahead sensor information?

21. At what altitude does the crew no longer need windshear alerting or look-ahead information for takeoff and approach?

22. What would be the benefits to crews, given look-ahead information, of "avoidance" maneuvers in other than the vertical plane?

23. What level of interaction between forward-look displays and present day color weather radar displays produces the greatest crew awareness of the windshear hazard?

24. What are the benefits to crews if alerted on positive (energy increasing) shears of the same magnitude as negative shear alerts detected by look-ahead sensors?

25. How do crews react and perform given windshear alerts on an aircraft that normally carries a look-ahead system and a reactive system and one of these systems are known to be inoperative?

26. What would be the benefits to crews to use voice in look-ahead situations for crew alerting?

Name ____________________

Organization ________________

27. What are the effects on pilot performance given a look-ahead windshear alert in instrument conditions as compared to a clear air dry microburst situation?

28. What are the tradeoffs in crew capability and reaction to either warning alerts given by forward-look devices or caution alerts given by forward-look devices as related to the distance to the windshear hazard?

29. What are the effects of the increased response time available to the crew with look-ahead windshear detection equipment?

30. What is the effect on response time and accuracy to a reactive system when look-ahead information is used as a precursor to the reactive alert?

31. What is the influence of achievable precision of look-ahead sensors on total effectiveness of the windshear detection system?

32. What are the benefits to crews of various update rate capabilities of look-ahead sensors?

33. What are the benefits to crews in the tradeoffs of increased accuracy as compared to range capability of look-ahead sensors?

34. What would be the benefits of crews knowing or not knowing which system (look-ahead or reactive) triggered a warning alert if just given a warning light and voice command of "windshear, windshear"?

OTHERS.. .

Appendix II

Comments from Issues Survey

1) Identify non-critical shears - Serious - any forward experience would be valuable, Serious - especially if the crew can derive rates of change or degree of fluctuation and infer possible future hazard, Desirable - Marginally(adds to clutter of info), Desirable- they don't represent a hazard so don't display, Serious - reduce unnecessary displays.

2) Actual velocities displayed to crew - Serious - I would think in some form, Critical - don't display additional data unless it's meaning is well clear to the pilot, Critical- derived OK, but keep it simple, Desirable - actual numerical readout may not be as good as some generic level of intensity indicator, Serious - reduce unnecessary displays.

3) Distance in-front of the aircraft to avoid - Critical - Basic system requirement, Serious - 15 to 30 seconds, Serious - this should be a standard for each class of aircraft, Critical - 30 to 60 seconds (depends somewhat on phase of flight), Critical - depends upon level/severity of the shear. Enough time to prevent unsafe flight/maneuver from 5th percentile pilot, Critical - distance will determine escape plan and locate the hazard for others, we can't look too short or too far to be useful.

4) How far displaced from the centerline - Serious - +or-20 degrees, Serious - secondary system requirement, Critical - widely enough to provide advanced maneuvering planning for precision, non-precision, and missed approach, Critical - +or-1/2 mile of the flight path, Serious - depends on the altitude and intensity of the shear. Selective presentation to pilot based on projected energy state and probability of encounter, Critical - ATC constraints dictate some maneuvering options but pilots must be aware if a lateral threat exists.

5) Guidance commands start when? - Serious, immediately upon system analysis that the shear is unsafe for landing, even though not in conditions yet, Critical - greater than 50 feet above runway during approach or after takeoff, Serious - at ranges corresponding to immediate to 30 seconds ahead and at any critically low altitude (below 300 feet), Critical - this is a basic systems requirement, Serious - less than 1000 feet AGL and within 10 seconds of an encounter, Serious - guidance commands that are strictly windshear related should only be displayed and followed when it's use is required.

6) 3-D view of hazard? - Serious, primary factor in usability/acceptability of system, Critical - none unless it was well integrated with other flight deck information- guidance info on a HUD would be better, Desirable - no benefits unless worked into a HUD, Desirable - Sounds like potentially the best display format, Desirable - very long term potential but not required for near term safety.

7) Can look-ahead information be integrated successfully into conventional and electronic flight decks? - Critical- Major implementation issue that effects feasibility and time for airlines to accommodate recommended changes, Critical - Why not, formats may not be the same but crew actions should be, Critical - must be well integrated with other flight deck information, it must be done this way to so as to minimize flight deck interference at critical flight phases, Serious - probably, Critical - initial efforts should be made to insure a system would work with both types of flight decks.

8) Crews see microburst movement? - Serious, secondary system requirement, Critical - not a benefit if crew is given the additional task of assessing potential threat while conducting other flight tasks, Critical - if trend shows it impacting flight path, Desirable - future desirable feature dependent upon display format/media, Desirable - Aircraft speed such that microburst travel not a factor; however, if this information interacts with ground sensors and other airborne equipment the trend information may be quite valuable.

9) Raw wind readout versus relative wind information - Serious - Method of info display would be critical, Desirable - raw wind would require interpretation and just create confusion, Critical - not a benefit because it requires interpretation by skilled observer, could possibly require extra crew member for data processing, No - crew has not got the time to analyze wind fields, Desirable - raw wind requires extra interpretation and is not directly related to aircraft performance (a 20 knot relative loss is easily understood as performance decreasing), Not an issue, Present LLWAS has shown raw winds to be confusing.

10) Control of look-ahead field of view - Desirable - Could give crews option while taxing, holding, or an approach of scanning ahead for the potential, could be automated, Desirable - no, at least not initially because of high training costs, Critical - Many departures and most approaches are curved. Therefore allow a scan of 90 degrees, Serious - giving pilots a measure of control would probably enhance acceptance, use, and benefits of

the system, Critical - must determine the required field of view for the hazardous situation.

11) Benefits of crew selectable parameters - Desirable - would probably enhance pilot acceptance, Critical - similar to those for on-board weather radar(tops, breath, etc.), Desirable - parameters should be standard with corrections for aircraft body angles, crab, pitch, etc., Serious - to much to do on approach should be standardized and automated here, however on the ground this would allow a better view of potential hazard and pilot acceptance.

12) Optimal Crew Operations Procedures Serious - Needed for display and system design, Critical - if look-ahead is deployed, it should be a spring-loaded push button returning to normal mode after a few seconds of look-ahead, Critical - use it to scan anticipated flight path/ Go-No Go decisions, Desirable - full auto scan and operations, limit crew options and indecisions, Serious - poor procedures can be identified and most effective methods quantified.

13) Will pilot control make system more acceptable? - Serious - surely they'll demand it, but, as with crew procedures it should be strictly controlled, Serious - it's the point of "utility" The same issue arises with airborne weather radar, Serious - full auto alerting system and manual override of controls would be very important, Serious - a determination must be made of system effectiveness and usage in auto only vs pilot control.

14) Alert on energy increasing shears? - Desirable, "increasing" shears are of interest... but not a hazard, Serious - if the correlate and associate with subsequent energy decreasing shears, Serious, shears should be alerted to pilot with appropriate information (+,-) and or with appropriate guidance, Serious - must be able to see the negative side of windshear before alerting otherwise nuisance will be great.

15) Magnitude of change despite low rate of change - Serious, it shows the amount of energy correction required, very important to flight control, Desirable - Little (it's the rate that counts), Serious - should not show things that are not hazardous as it is not the purpose of the system and nice to haves may just upset the workload, Serious - reduction of superfluous information.

16) What nuisance alert rate is acceptable - Serious - must be careful here or you will have GPWS problems, Serious - Should be very low rate or it will "numb" the crew or exacerbate workload, Serious - less than one it ten, FSS and NOAA weather are already in disrespect due to high

"false alarm rate", Critical - We can't afford to be spending lots of money on another cry wolf system.

17) What missed alert rate is accentable - Critical- Basic system requirements, Critical- one in a hundred, and then only because the shear was on the benign side, Critical - Anything impacting the prospective flight path that could be hazardous must be detected, Critical - SAE wants 10-4, it must detect the hazard to be viable, Critical - this must be determined as windshear has such a variance in duration and intensity.

18) What false alert rate is acceptable - Critical- too high a false alarm rate can kill a program and a system, Serious - one in 20, Critical - must be very low but remember...just because not encountered does not mean not there originally, Critical - Almost none, otherwise it will be seen as crying wolf, Critical - electronics problem, should be very low.

19) Crew react in executive or advisorv manner - Critical - warning and time critical both ought to be executive, Critical - "advisory" unless company procedures make it executive depending upon thresholds and magnitudes and proximity, Desirable - political question, Serious - need to resolve this in order to plan appropriate procedures for certification. It may be necessary to mandate as an executive alert with a guidance implementation, Critical - the time available to respond may require the system to be executive out to a certain range and then beyond that give them the options of an advisory system.

20) Reactive svstems rescheduled bv look-ahead information - Desirable- as the names imply, the more lead that is put into the flight management equation the smoother and safer the flight, Serious - I do not see this happening, though. They are independent. The former is Executive in nature and the later is Advisory because of the time element,-Serious - best of both worlds provided combined reliability is there, Serious- if the forward-look reliability is less than perfect than you may be changing a good system with the use of bad information.

21) What altitude does alerting and information stop - Critical - based on airplane energy state and altitude above the ground, Serious - above 2000 feet, Critical info below 2000 feet, turbulence (CAT) information useful enroute, Critical - basic system requirement, Desirable - above 500 feet AGL, Critical - based on aircraft speed, intensity of the downburst, and altitude there is an energy state which alerting not required.

22) Maneuvers in other than the vertical plane - Critical - must not be accomplished below some critical maneuvering

altitude (e.g. 200 feet AGL), Critical - Operationally useful but not below a minimum altitude, say 250 feet AGL, Desirable - Mostly be concerned with the area on short final, close to the ground, with little maneuver space, Critical - a region should be established where, within ATC constraints, lateral maneuvering would be the best choice, however time critical areas should only have one method of choice to get proper reaction time.

23) Interaction between look-ahead and weather radar - Critical - High interaction color weather radar will probably be the information vehicle, Critical - must be consistent in display interaction, Desirable - only one method of display among lots of options, Critical - must alert the type of windshear sensed, eg. downburst, lateral, vertical etc. and severity - appropriate CRT warnings should be developed.

24) Alert on positive (energy increasing) shear detection and negative shear magnitude? - Serious - crews need to understand the need to react appropriately to each type of shear, Serious - depends on the interrelationship, not all microburst are symmetrical, Critical - the combination spells the classical microburst, Serious - nuisance should be weighed as compared to the time to see the entire windshear.

25) One system is inoperative? - Serious - like any other system, if on the MEL they note the degraded capability and try to remember the specific limitations, Serious - They do the best they can as they do today. It's very important to know if a system is inoperative, however, and which one, Serious - depends on how the systems are integrated and capabilities when degraded, Critical - need to determine this for MEL certification.

26) The use of voice - Serious - need to determine this in simulation-follow on to Flight Phase Status Monitor, Desirable - probably not if look-ahead is advisory, Critical - a workload shedding capability...It's needed, Serious - we must be consistent in alerting and the use of voice when no immediate action is required is inconsistent.

27) Look-ahead in dry air or wet microburst situation - Serious - Design for instrument conditions and test for acceptability for both, Serious - the wet microburst tends to be executive and the dry microburst tends to be advisory, Desirable - need to determine appropriate alerts and procedures given typical pilot responses for each different shear type, Serious - alerts and procedures should be the same for each type however they should be looked at for pilot reaction in both types of conditions.

28) Tradeoffs of Warning or Caution depending on distance - Serious - need to determine this in simulation, needs to be determined for MEL certification, Serious - again, relates to previous question. If magnitude, location and distance (N.M. or seconds) given, then we keep alerts in "caution" or "advisory" category and crew can make a go/no go decision, Critical - a biggie to test and evaluate, Critical - must determine the point at which pilots will be given a warning and must react.

29) Effects of increased resnonse time available - Critical - a physical measurement that must be determined in order to insure a safe warning time, Critical - It would allow for more informed decision making. The Dallas crash might have been averted by an earlier abort, Serious - basic system capabilities need to be determined, Desirable - the more lead time the better and safer the flight will be, however if we are lead time limited due to reliability of the alerts then we must determine the effects of particular lead times, Critical - this physical measurement must be done.

30) Reactive response time changes using look-ahead precursor - Serious - needs to be determined by simulation what the best way to combine use of the systems might be, Critical - basic systems capability of it's effect on other associated warning systems must be known, Serious - will only be a factor if the look-ahead system is only advisory in nature, Would be silly response to look-ahead because the system would not have worked.

31) Achievable Precision effects on svstem - Serious - Airlines will be better able to set policy based on definitive data, Serious - needs to be determined by simulation, Critical - the precision of the information will effect nuisance and directly effect overall system effectiveness.

32) Effects of update rate capabilitv of sensors - Serious - Airlines will be better able to set policy based on definitive data, Desirable - needs to be determined by simulation in order to determine best usage, Serious - the effects of different update rates should be evaluated as compared to how quickly the windshear can build or dissipate.

33) Accuracv versus Ranae Canabilitv - Critical - this could be a good candidate for the simulator, especially for the takeoff problem, Serious - it better enables the Go-No Go decision and the airlines policy makers. One needs the most accuracy possible even if you trade 60 seconds look-ahead for only 15-30 seconds, Critical - tradeoffs will have to be made in this area and should favor what pilots perceive to be system effectiveness.

34) <u>Benefits to crews to know which system caused alert</u> - Critical - should know if pilots reacts differently knowing which system went off, Critical - this will determine if the look-ahead alerting display for time critical situations can remain the same as is already in the airplane today, Critical - will allow an assessment of variance to the same alert dependent on the altitude it is received.

3

Appendix III

Crew Interface Issues For Advanced Airborne Windshear Detection systems

Developed by Boeing Commercial Airplane Company Flight Deck Research

Abstract

This paper documents the efforts of the Boeing Commercial Airplane Company-Flight Deck Research Group to compile and categorize crew interface issues regarding Advanced Airborne Windshear Detection Systems; This paper is modeled after the Human Engineering Issues for the Traffic Alert and Collision Avoidance System developed by the SAE G-10 TCAS Subcommittee. The flight crew has expanding windshear information sources with the probability that look-ahead sensors may be added to present windshear detection capabilities. Previous experience with improved airborne sensors reveals that crew interface issues need to be addressed before systems are put into industry wide operation. The primary purpose of this work is to provide a central source for tracking research activities on crew interface issues concerning advanced airborne windshear detection systems (those windshear systems that include look-ahead capability). It is intended that this paper be a "living" report on the relevant crew interface issues and it will be updated regularly to reflect research activities. The material in this document is maintained on an IBM PC using RBase System V data base software to make available a continuously updated source of information.

The objectives of this paper are: to identify current relevant crew interface issues; to categorize the issues relative to implementation impact and research priorities; to provide requirements for research activities to address the issues raised; and to provide a source of information concerning relevant crew interface issues to industry to assist them in the design and manufacturing of advanced airborne windshear detection systems. The scope of this document is limited to crew interface issues, problems, and requirements relevant to advanced windshear detection systems.

The material contained in this document is a result of the efforts of the Boeing Commercial Airplane Company-Flight Deck Research Group. The Flight Deck Research Group conducted this work as part of a NASA contract to conduct windshear studies. The issue determination and implementation impact was determined by a survey of windshear technologists, researchers, aviation regulatory members, pilot groups, and human factors experts. This document reflects a consensus opinion of these groups. The scope of this document is designed to address new issues as they may develop with expanding technology. Any comments or information Concerning the issues contained in the document should be directed to the Boeing Flight Deck Research Group.

Introduction

The flight crew has many information sources available to cope with dangerous windshear situations. These information sources are expanding with the probability that look-ahead sensors may be added to present windshear detection capabilities. Understanding what information the crew needs becomes increasingly important as flight crews seek, with the aid of advanced sensors, to avoid entering hazardous windshear conditions. The introduction of look-ahead sensors as a natural next step in windshear

detection reveals crew information issues that need to be resolved. We must determine how much data and information the crew needs and the integrated presentation concepts, which consider the pilot's workload and operational constraints, that should be adopted.

The resolution of these issues will assist in the development and implementation of improved windshear detection equipment.

Purpose

This document is a compilation of crew interface issues regarding advanced windshear detection systems. It is intended that the document be a continuously updated report on the extent of human factors work that is being conducted on these crew interface issues.

Objectives

The objectives for this particular effort involving advanced windshear detection systems are:

- To document the crew interface issues associated with advanced windshear detection equipment;
- To categorize the crew interface issues relative to their implementation impact and research priority;
- To provide requirements for research activities to address the issues raised;
- To provide a source of information concerning relevant crew interface issues to industry to assist them in the design and manufacturing of advanced airborne windshear detection systems.

Scope

The scope of this document is limited to crew interface issues, problems, and requirements of the implementation of advanced windshear detection equipment.

Definition of Issue (Implementation Impact) Categories

Critical

- Issue resolution required prior to industry-wide implementation

* An issue, if left unresolved:

1) Critically limits the operational capabilities of the system,
2) Critically affects pilot confidence in the system, or
3) Critically degrades flight safety in certain windshear situations.

Serious

* Should be resolved prior to industry-wide implementation

* An issue, if left unresolved:

1) Limits the operational capability of the system,
2) Affects pilot confidence in the system, or
3) Degrades flight safety in certain windshear situations.

<u>Desirable</u>

* **A** resolution of an issue could be expected to improve the physical and/or operational man-machine interface.

* An issue, if left unresolved:

1) Could limit the operational capability of the system,
2) Could affect pilot confidence in the system, or
3) Could degrade flight safety in certain windshear situations.

See Table 1 for the issue categorization.

Research Priorities

Within each Implementation Impact Category a provision is made to identify research priorities. The assignment of priority is based on the assessment of the issues by **NASA** Langley and Boeing Flight Deck Research. The priorities will be identified as a numerical value, the lowest of which represents the highest priority within each Implementation Impact Category.

TABLE 1

IMPLEMENTATION IMPACT AND RESEARCH PRIORITY OF LOOK-AHEAD WINDSHEAR DETECTION ISSUES

Entry Date: **03/15/88**

Issue Name	No.	Implementation Impact	Research Priority
Missed Alert Acceptability	17	critical	1
Distance Sensors Need to Look	03	Critical	1
False Alert Acceptability	18	critical	1
Nuisance Rate Acceptability	16	Critical	1
Effects of Pilot Operating Procedures	12	critical	2
Effects of Precision on System Effectiveness	31	critical	2
Effects on Accuracy with Improved Range Capability	33	Critical	2
Effects of a Azimuth Scanning Capability	04	Critical	2
Guidelines for Implementation on Displays	07	Critical	3
Implementation of Executive or Advisory Systems	19	critical	3
Implementation of Alerting as a Function of Distance	28	critical	3
Guidelines for Weather Radar Overlay	23	serious	4
Effects of Lateral Avoidance	22	serious	4
Effect of Alerting Activation as a Function of Altitude	21	Serious	4
Look-ahead Response Time Assumptions	29	Serious	4
Effects of Knowing Which System does Alerting	34	Serious	4
Effects of Reactive System Scheduling	20	Serious	5
Effects of Pilot Controlled Field of View	10	Serious	5
Effects on Reactive Responses with Look-ahead Information	30	Desired	5
Guidelines for Guidance Commands	05	Desired	5
Look-ahead in IMC Versus VMC	27	Desired	6
Effects of Actual Velocity Displays	02	Desired	6
Look-ahead Alerting Only on Positive Shear Rates	24	Desired	7
Views of Hazard	06	Desired	7
Effects of Update Rate Capabilities	32	Desired	7
Effects of Displayed Microburst Movement	08	Desired	7
Identification of Non-critical Shears	01	Desired	8
Uses of Voice	26	Desired	8
Partially Inoperative Systems Effect	25	Desired	8

Report Capabilities

These crew interface issues are maintained on an IBM PC microcomputer using RBase System V database software. The principal objectives of using this approach are to reduce the time required to research advanced windshear system crew interface activities, and make the results of.research work in specific areas easily accessible.

The report generation capability within the RBase software is very extensive, with recorded information easily retrieved and formatted in customized reports to satisfy the needs of it's users.

Table **2** presents the advanced windshear systems crew interface identification system which is used to retrieve issues on specific topics.

On the pages following Table **2,** each issue is described (one issue per page) in the form used in the RBase database. In addition to the description, the research priority, requirements and recommended approach, current activity, and conclusions (if any) are provided for each issue. (Note: the issue descriptions are not included in this report, but are available from the authors).

TABLE 2

LOOK-AHEAD WINDSHEAR ISSUES IDENTIFICATION SYSTEM

Issue Category	Sub-Category	Elements	Sub-Element	Code Number
General				A00.000
	Windshear Systems			A01.000
		Reactive		A01.100
		Look-Ahead		A01.200
			LIDAR	A01.210
			Radar	A01.220
			IR	A01.230
	Verification			A02.000
		Simulation		A02.100
		Airborne		A02.200
NAS				A10.000
	ATC			A10.000
		Collision Potential		A11.100
		Clearance Airspace		A11.200
	GPWS			A12.000
	Obstacle Clearance			A13.000
Caution/Warning				A20.000
	Aural			A21.000
	Cancel			A22.000
	Color			A23.000
	Location			A24.000
	Master			A25.000
	Symbology			A26.000
	Timing			A27.000
	Nuisance			A28.000
		Missed		A28.100
		False		A28.200
Crew Performance/Training				A30.000
	Response Time			A31.000
		Detection		A31.100
		Interpretation		A31.200
		Completion		A31.300
			Average Time	A31.310
			Distribution	A31.320
	Response Quality			A32.000
		Correctiveness		A32.100
		Decisiveness		A32.200
		Crew Coordination		A32.300
	Compatability			A33.000
		NAS Requirements		A33.100
		Operations Procedures		A33.200
		Anticipation		A33.300
	System Familiarity			A34.000
		Training		A34.100
		Frequency of Use		A34.200
	Workload			A35.000

TABLE 2 (Cont.)

Issue Category	Sub-Category	Elements	Sub-Elements	Code Number
		Visual Scan		A35.100
		Aircraft Performance		A35.200
		ATC Communication		A35.300
		Traffice Avoidance		A35.400
		Flight Phase		A35.500
Procedures				A40.000
	Go-Around			A41.000
		Windshear		A41.100
		Normal		A41.200
	Crew Coordination			A42.000
		Flying Pilot		A42.100
		Non-flying Pilot		A42.200
	Continued Approach			A43.000
	Avoidance			A44.000
		Vertical		A44.100
		Horizontal		A44.200
	Cancellation			A45.000
	Guidance			A46.000
	Thrust			A47.000
	Configuration			A48.000
Logic				A50.000
	TAU			A51.000
	Fusion			A52.000
	Interaction			A53.000
System				A60.000
	Advisory			A61.000
	Alert Frequency			A62.000
	Executive			A63.000
Display				A70.000
	visual			A71.000
		Controls		A71.100
		Location		A71.200
		Priorities		A71.300
		Content		A74.400
			Symbology	A71.410
			Size	A71.420
			Shape	A71.430
			Color	A71.440
			Clutter	A71.450
		Technology		A71.500
			LED	A71.510
			EFIS	A71.520
			EADI	A71.530
			Standard	A71.540
		Timing		A71.600

Appendix IV

Pilot Briefing Checklist

1.0 Introduction

1.1 Background

a. This is a NASA contract with Boeing Flight Deck Research to conduct windshear studies.

b. The emphasis of these studies is on the crew interface with advanced windshear systems.

c. These advanced windshear systems will include look-ahead windshear detection information as well as reactive windshear detection devices.

d. The initial phase of these crew interface studies includes identifying and categorizing the functions of the alerts.

e. A test is being conducted to determine regions where look-ahead windshear detection devices should alert crews in a time-critical warning manner.

You will participate in this test!

1.2 Objectives

a. To augment the existing windshear data base of information on caution and warning signals to include look-ahead alerting trials.

b. Provide data on the effects of look-ahead alerting and go-around techniques for the use of look-ahead windshear detection equipment.

c. Allow comparisons of warning alert crew requirements with look-ahead detection capabilities.

d. Evaluate the time-critical look-ahead presentation media.

e. Evaluate the NASA Windshear model in piloted simulation.

2.0 Flight Task

2.1 Active Displays

a. EADI

b. HSI/DME

c. Airspeed

d. Altimeter

e. Vertical Speed

f. Clock

g. Alert display(s)

h. Engine instruments

i. Flap position indicator

2.2 Active Controls

a. Wheel and Column

b. Rudder and toe brakes

c. Speed Brake

d. Flaps

e. Gear

f. Throttles

g. Autothrottle

h. Autopilot

3.0 Crew Alerting

3.1 Look-Ahead Alerting

a. Windshear warning light bar will illuminate when the look-ahead windshear system has detected a windshear. This windshear has been evaluated as a hazard to flight and at a range that requires immediate awareness and a go-around. This warning is time critical in nature and your immediate response is the most important action you can take.

b. An aural warning will sound with the activation of the light bar to provide a voice warning. The voice will follow alerting guidelines and tell you of the warning and the appropriate action. The voice message will be "Windshear - Go Around",

3.2 Reactive Alerting

a. The reactive windshear system will still operate in the normal manner. The reactive warning displays and voice will function normally and should be understood to be part of an advanced windshear system that contains both detection methods.

4.0 Sensor Discussion

4.1 Look-Ahead Sensors

a. Doppler Radar

b. Doppler Laser (Lidar)

c. IR sensors

4.2 Reactive Sensors

5.0 Windshear Model

5.1 NASA model development

5.2 Look-Ahead technologist use of the model

6.0 Evaluation Flights

6.1 windshear Go_Around

a. Pilots will receive the look-ahead warning at various times while on final approach. The warning times will vary as a function of the time and distance to the windshear core. The pilots will execute a windshear go-around in accordance with the procedures spelled out in the windshear training guide. The go-around will be initiated by depressing the TOGA levers. The pilot will terminate the individual flight upon reaching a condition which the pilot evaluates the windshear hazard to not exist.

b. Review windshear training guide for windshear recovery procedures

6.2 Normal Go-Around

a. Pilots will receive the look-ahead warning at various times while on final approach. The warning times will vary as a function of the time and distance to the windshear core. The pilots will execute a normal go-around in accordance with the procedures published in the flight manual. The go-around will be initiated by depressing the TOGA levers. The pilot will terminate the individual flight upon reaching a condition which the pilot evaluates the windshear hazard to not exist.

b. Review normal go-around procedures

6.3 Alerting variations

a. Several times during the testing the look-ahead system will appear to be inoperative or the reactive system will appear to be inoperative. Proceed to take action in the normal manner. Should you encounter windshear conditions without any advanced warning take the appropriate action that the situation dictates.

6.4 Post-Flight Ouestionnaire

a. After each flight a quick set of questions will be asked about the alerting and windshear encountered.

7.0 Debriefing Questionnaire

Debriefing questions will be given regarding the windshear model, alerting, crew procedures, and alert timing.

Appendix V

Post-Flight Questionnaire

Pilot____________________

1. Was the warning alert given too much in advance of the windshear encountered such that it did not require your immediate awareness and immediate corrective action?

   E=early
   L=late
   O=about right

2. If you concluded that the warning alert required immediate awareness and immediate corrective action and was appropriate, or came too early, what influenced you to come to that conclusion (parameters when you received the alert, those encountered, etc.)?

3. What factors (altitude, airspeed, WI, etc.) influenced you to determine that you were safely out of the hazardous region? List these factors.

4. Do you conclude that this advance warning was time critical in nature and required your response using the go-around method you used?

5. Was the shear you encountered of a hazardous intensity? Why?

6. Do you have any general observations or comments about conditions or flight parameters that should dictate alerting (either the level of the alert, when it starts, or when the alert should end)?

7. Any additional comments?

Appendix VI

Debriefing Questionnaire

1. Do you think this NASA windshear model accurately simulates a windshear event that is severe and represents a hazard? Any Comments?

2. Do you think illumination of the light bar and the voice message adequately made you aware of the situation immediately and prompted an immediate response?

3. Do you have any comments on the time critical warning media-the light bar and voice? Do you have any changes you would make?

4. Did the combination of reactive warning and look-ahead warning create any confusion?

5. If you had to choose one technique for a go-around given an adequately timed warning alert, which method would you choose?

6. Do you have any general observations or comments about conditions or flight parameters that should dictate alerting (either the level of the alert, when it starts, or when the alert should end)?

7. Any additional comments?

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Appendix VII
Data from Alerting Simulation

Session #1

Trial Order	Subject	Timing of Predictive Alert: Time Before Microburst Core (SEC)	Time Before Reactive Alert Should Have Triggered (SEC)	Recovery Maneuver Effects: Altitude Reactive Alert Activated (FEET)	Was There A Sink Rate At Less Than 600 Feet?	Minimum IAS During Recovery (KNOTS)	Maximum F Factor Encountered $\left(F = \frac{Wx}{g} - \frac{Wh}{v}\right)$	Pilot's Estimate of Whether Look-Ahead Alert Timing Was Early (E), About Right (AR), or Late (L)
1.	16	52	31	1280	N	124	.27	AR
2.	*	27	6					
3.	*	21	0					
4.	17	47	26	1100	N	129	.28	AR
5.	*	32	11					
6.	18	37	16	940	N	127	.25	L
7.	*	32	1					
8.	13	42	21	860	N	119	.22	L
9.	2	29	8	880	N	132	.22	L
10.	15	57	36	1460	N	125	.30	E/AR
11.	4	52	31	980	N	136	.24	AR
12.	5	27	6	360	N	130	.20	L
13.	7	21	0	240	N	130	.19	L
14.	9	47	26	700	N	136	.22	AR
15.	10	32	11	420	N	135	.20	L
16.	11	37	16	500	N	134	.22	L
17.	12	22	1	360	N	125	.18	L
18.	1	42	21	900	N	136	.22	AR
19.	*	29	8					
20.	3	57	36	1280	N	136	.30	E

* DATA MISSING

Appendix VII
Data from Alerting Simulation

Session #2

Trial Order	Subject	Timing of Predictive Alert: Time Before Microburst Core (SEC)	Timing of Predictive Alert: Time Before Reactive Alert Should Have Triggered (SEC)	Recovery Maneuver Effects: Altitude Reactive Alert Activated (FEET)	Recovery Maneuver Effects: Was There A Sink Rate At Less Than 600 Feet?	Recovery Maneuver Effects: Minimum IAS During Recovery (KNOTS)	Recovery Maneuver Effects: Maximum F Factor Encountered $\left(F = \frac{W_x}{g} - \frac{W_h}{v}\right)$	Pilot's Estimate of Whether Look-Ahead Alert Timing Was Early (E), About Right (AR), or Late (L)
1.	3	52	31	1500	N	122	.3	AR/L
2.	4	27	6	440	Y	116	.20	L
3.	15	21	0	240	Y	117	.20	L
4.	6	47	26	1280	N	123	.28	L
5.	8	32	11	540	Y	117	.22	L
6.	10	37	16	440	Y	117	.21	L
7.	11	22	1	320	N	115	.19	L
8.	13	42	21	700	N	120	.22	L
9.	1	29	8	600	Y	115	.21	L
10.	2	57	36	1400	N	130	.30	AR
11.	18	52	31	1140	N	136	.30	AR
12.	19	27	6	380	N	131	.20	L
13.	20	21	0	250	N	118	.20	L
14.	23	47	26	1140	N	138	.26	AR
15.	22	32	11	440	N	134	.21	L
16.	24	37	16	460	N	137	.22	AR
17.	26	22	1	260	N	124	.19	L
18.	28	42	21	580	N	137	.21	AR
19.	16	29	8	Did Not Go Off	N	120	.21	AR/L
20.	17	57	36	Did Not Go Off	N	134	.27	AR

* DATA MISSING

Appendix VII
Data from Alerting Simulation

Session #3

Trial Order	Subject	Timing of Predictive Alert		Recovery Maneuver Effects				Pilot's Estimate of Whether Look-Ahead Alert Timing Was Early (E), About Right (AR), or Late (L)
		Time Before Microburst Core (SEC)	Time Before Reactive Alert Should Have Triggered (SEC)	Altitude Reactive Alert Activated (FEET)	Was There A Sink Rate At Less Than 600 Feet?	Minimum IAS During Recovery (KNOTS)	Maximum F Factor Encountered $\left(F = \frac{W_x}{g} - \frac{W_h}{v}\right)$	
1.	4	52	31	1020	N	123	.22	AR/E
2.	3	27	6	300	Y	110	.18	L
3.	5	21	0	230	N	120	.20	L
4.	6	47	26	1020	N	128	.28	AR
5.	7	32	11	500	N	112	.21	AR/L
6.	8	37	16	600	Y	110	.20	AR
7.	9	22	1	320	Y	108	.17	L
8.	10	42	21	740	Y	111	.21	L
9.	12	29	8	320	Y	106	.17	L
10.	2	57	36	Did Not Go Off	N	128	.27	AR/E
11.	15	52	31	Did Not Go Off	N	140	.21	E
12.	14	27	6	Did Not Go Off	Y	112	.19	AR
13.	23	21	0	200	Y	110	.18	L
14.	17	47	26	800	N	138	.28	E
15.	20	32	11	340	Y	118	.18	AR
16.	22	37	16	500	N	121	.21	E
17.	24	22	1	240	Y	110	.18	L
18.	25	42	21	680	N	137	.21	E
19.	26	29	8	380	N	122	.19	AR
20.	13	57	36	1150	N	140	.27	E

* DATA MISSING

Appendix VII
Data from Alerting Simulation

Session #4

Trial Order	Subject	Timing of Predictive Alert: Time Before Microburst Core (SEC)	Timing of Predictive Alert: Time Before Reactive Alert Should Have Triggered (SEC)	Recovery Maneuver Effects: Altitude Reactive Alert Activated (FEET)	Recovery Maneuver Effects: Was There A Sink Rate At Less Than 600 Feet?	Recovery Maneuver Effects: Minimum IAS During Recovery (KNOTS)	Recovery Maneuver Effects: Maximum F Factor Encountered $\left(F = \frac{Wx}{g} - \frac{Wh}{v}\right)$	Pilot's Estimate of Whether Look-Ahead Alert Timing Was Early (E), About Right (AR), or Late (L)
1.	3	52	31	1380	N	111	.28	E
2.	4	27	6	540	Y	111	.19	L
3.	17	21	0	280	Y	113	.21	L
4.	6	47	26	740	N	112	.24	AR
5.	7	32	11	440	Y	112	.21	AR/L
6.	8	37	16	500	Y	112	.21	AR
7.	10	22	1	520	Y	110	.21	L
8.	11	42	21	400	Y	110	.22	AR
9.	13	29	8	340	N	111	.19	L
10.	14	57	36	1480	N	114	.30	E
11.	18	52	31	1056	N	139	.28	AR
12.	19	27	6	300	Y	112	.19	L
13.	20	21	0	260	N	114	.19	L
14.	22	47	26	780	N	133	.23	AR
15.	23	32	11	360	N	130	.19	AR/L
16.	24	37	16	440	N	130	.21	L
17.	26	22	1	480	N	120	.19	L
18.	29	42	21	460	N	133	.22	AR/L
19.	30	29	8	400	Y	112	.19	L
20.	32	57	36	1160	N	140	.29	E

* DATA MISSING

Appendix VII
Data from Alerting Simulation

Session #5

Trial Order	Subject	Timing of Predictive Alert: Time Before Microburst Core (SEC)	Timing of Predictive Alert: Time Before Reactive Alert Should Have Triggered (SEC)	Recovery Maneuver Effects: Altitude Reactive Alert Activated (FEET)	Recovery Maneuver Effects: Was There A Sink Rate At Less Than 600 Feet?	Recovery Maneuver Effects: Minimum IAS During Recovery (KNOTS)	Recovery Maneuver Effects: Maximum F Factor Encountered $\left(F = \frac{Wx}{g} - \frac{Wh}{v}\right)$	Pilot's Estimate of Whether Look-Ahead Alert Timing Was Early (E), About Right (AR), or Late (L)
1.	14	52	31	1200	N	128	.26	AR/E
2.	1	27	6	450	Y	113	.21	L
3.	3	21	0	240	Y	120	.21	L
4.	4	47	26	840	N	127	.21	L
5.	8	32	11	380	Y	118	.21	L
6.	9	37	16	520	Y	115	.21	L
7.	10	22	1	380	Y	116	.22	L
8.	11	42	21	720	N	121	.22	AR
9.	12	29	8	420	Y	115	.21	L
10.	13	57	36	1480	N	122	.27	E
11.	25	52	31	1320	N	136	.25	AR
12.	15	27	6	360	N	135	.21	L
13.	16	21	0	280	N	129	.20	L
14.	17	47	26	820	N	134	.23	L
15.	20	32	11	380	N	128	.22	L
16.	21	37	16	380	N	125	.20	L
17	*							
18.	23	42	21	580	N	127	.22	L
19.	24	29	8	400	N	127	.21	L
20.	26	57	36	Did Not Go Off > 1500	N	136	.27	E

* DATA MISSING

APPENDIX VIII
A CREW ALERTING *AND* PROCEDURES SURVEY FOR LOOK-AHEAD WINDSHEAR DETECTION SYSTEMS

As part of a contract task under the NASA/FAA Airborne Windshear Program, the Boeing Flight Deck Research group is developing a prototype structure for a Crew Alerting/ Procedures Model for the future look-ahead windshear detection system environment. A preliminary concept flow diagram is shown in Figure 1. The portion of the flow diagram enclosed within the dotted line is of primary interest to us and we need your help in selecting appropriate criteria for each alerting level, and in determining crew procedures to follow each level of alerting.

We have structured the flow around a series of alerting levels which are consistent with most current alerting system recommendations and practices. While many operational systems employ only the three alerting levels of "warning, caution, and advisory", the fourth level, that of "time-critical alert", has been added to explore whether this is a relevant, and distinct, level of alerting for the look-ahead windshear environment. For purposes of this survey, this level is differentiated from "warnings" in that it would require an unconditional and immediate aircraft maneuver response by the pilot rather than an immediate, but deliberate and considered, response that is often oriented to aircraft systems or attitude problems. It is desirable that the alerting philosophy used for windshear alerts be consistent with the recommended alerting guidelines currently advocated for most commercial operations. These guidelines have been adapted by Flight Deck Research to define the following alerting categories for use in this prototype model:

A) ADVISORY ALERT: Operational or system condition that requires prompt crew awareness and may require subsequent or future crew action;

B) CAUTION ALERT: Abnormal operational or system condition that requires immediate crew awareness and subsequent corrective or compensatory crew action;

C) WARNING ALERT: Emergency operational or system condition that requires immediate crew awarness and rapid corrective or compensatory crew action;

D) TIME-CRITICAL ALERT: Critical operational, system, or external condition that requires immediate, corrective or compensatory crew action, usually consisting of a flight path maneuver.

Other current executive-level warnings that require a maneuver response from the crew, such as with some GPWS and TCAS situations, might also be grouped, along with the most critical windshear conditions, into this "time-critical" category. For

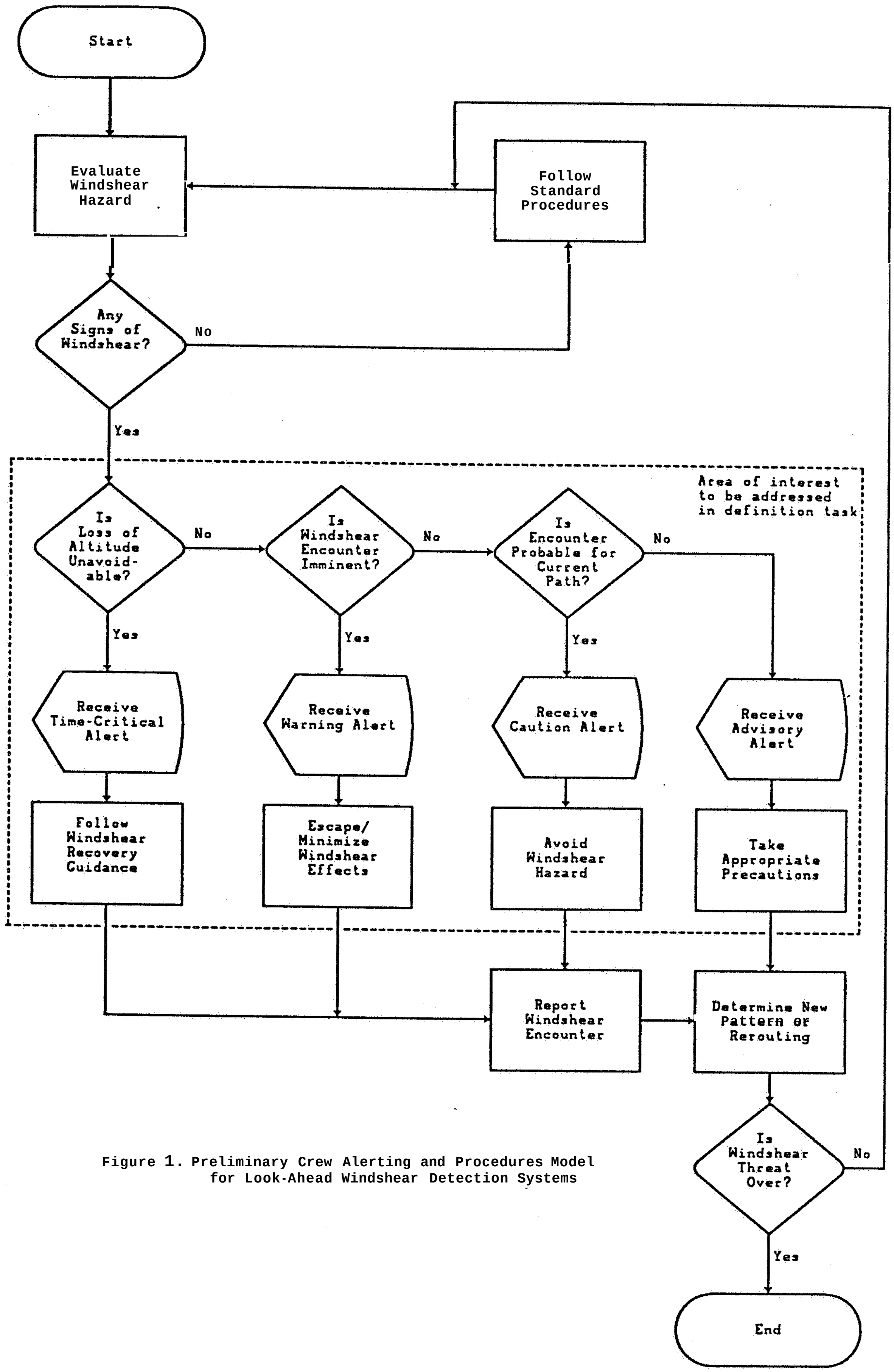


Figure 1. Preliminary Crew Alerting and Procedures Model for Look-Ahead Windshear Detection Systems

reference, the alerting levels currently described in ARP4102/11 consist of the following:

"2.2.7 Windshear Advisory Alert: An alert which is set at a windshear level requiring crew awareness and may require crew action. (Advisory Condition, Level One, ARP4102/4)

2.2.8 Windshear Caution Alert: An alert which is set at a windshear level requiring crew awareness and may require crew action. (Abnormal Condition, Level Two, ARP4102/4)

2.2.9 Windshear Warning Alert: An alert which is set at a windshear level requiring immediate corrective action by the crew. (Emergency Condition, Level Three, ARP4102/4)"

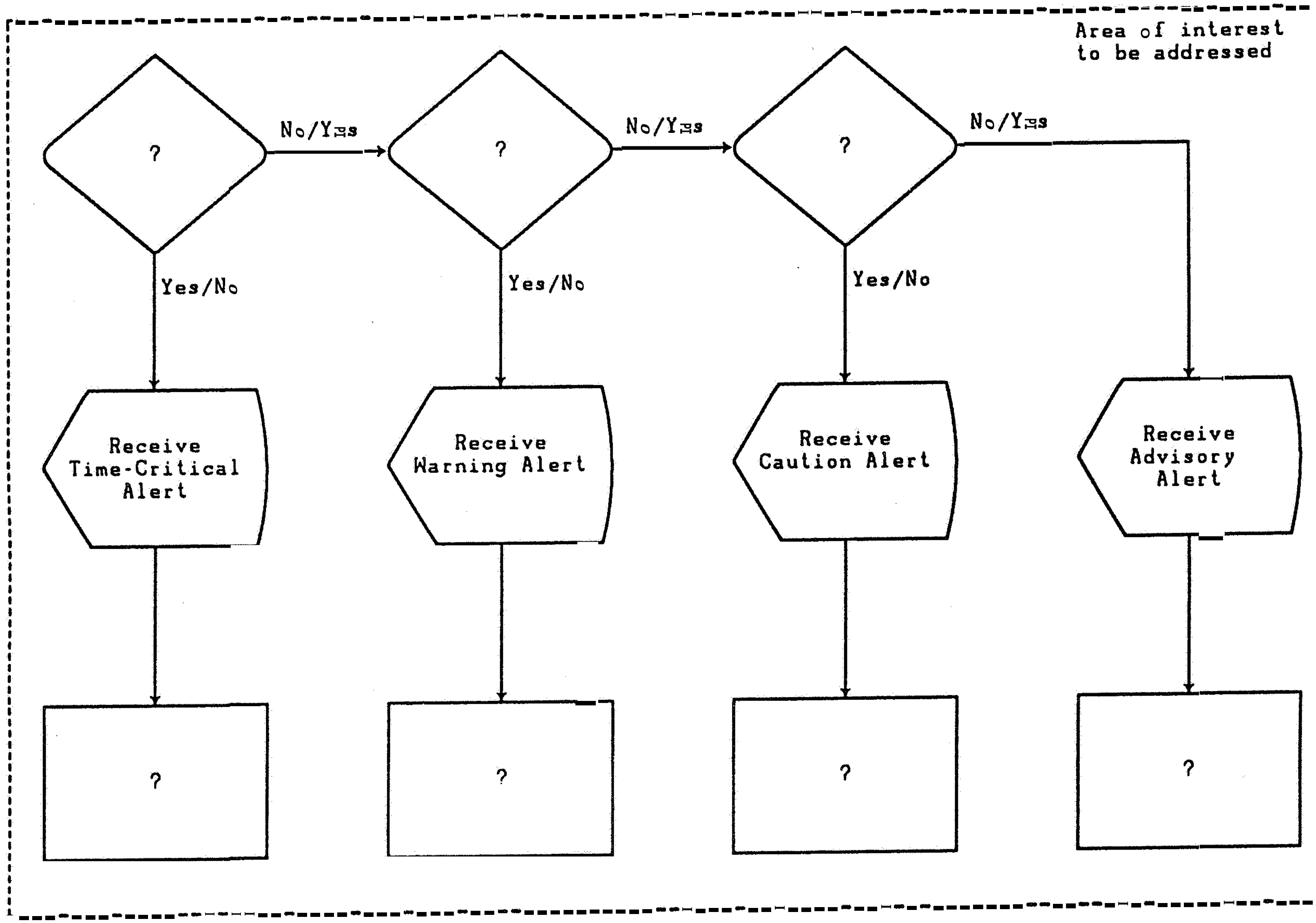
One of the inputs we would like to have from you is whether you think all four of these alerting levels are appropriate for the look-ahead windshear detection environment, or whether only one, two, or three of the levels should be used. Or perhaps you believe a different type or set of alerts should be used for windshear. If you conclude, after due consideration, that the entire scheme shown is the wrong approach, we would appreciate that you take the extra time to sketch out a scheme that you would prefer to see used -- just use the last (blank) page to describe your concept. Even so, we would like your input on the proposed structure, consistent with the alerting scheme shown in the flow chart.

In Figure 2, you will find an enlarged copy of that area of the flow chart that we are interested in, with a number of the decision(criteria) points, and procedure cells, left blank(with question marks). We would like you to take a shot at filling in the blanks -- the three top diamond shapes need decision questions that you feel best represent the criteria that should be met for each associated alerting level, while the four rectangular procedure boxes need statements that you feel best summarize the crew procedures that should follow each of the alert conditions. Keep in mind the crew-response-oriented definitions for the different alerting levels.

Select a single heading to be entered in each of these blocks -- you may use one or more of the sample headings shown in the overall flow diagram if you feel they best describe the set of criteria or procedures you associate with that level -- but don't use them just because we provided them. For example, you may want to specify a systems or environmental condition such as: "Airspeed/groundspeed differential > 40 kts", as the criterion that the alert should be based upon. You may make it as simple or as complex as you feel is warranted by the operational conditions (workload, time constraints, etc.).

Depending upon how you end up phrasing the criteria questions, just cross out the inappropriate alternative(Yes or No) in each case for the decision points so that the correct flow logic is

Figure 2. Primary Area of Interest in Crew Alerting and Procedures Model



indicated. If you come up with a list of criteria for one or more of the decision blocks, and don't want to indicate a single "heading", just use "Time-Critical Alert Criteria" or some such, and list each of the criteria on the description sheets which follow Figure 2.

You may prefer to postpone the step of selecting the headings until after you have completed the next step -- that of describing each block. On the two pages following Figure 2, you will find a set of eight blank sections. We would like you to list or describe the specific criteria you would specifiy as the necessary conditions for generation of the individual alerts, and then each crew procedure or consideration that you feel areassociated with, and unique to, each of the alerting levels you have picked(or that are shown). The following paragraphs contain additional background that is related to this task, and may be useful in your selection of criteria and procedures.

The windshear sensors being considered for airborne, look-ahead detectors include doppler radar, IR, Lidar-based systems, and perhaps others. Since any one of these does not appear to have adequate capabilities for the variety of windshear events that pose significant threats (both wet and dry microbursts for instance), probably a combination(s) will be developed as the preferred configuration. The look-ahead sensors will basically be able to detect microburst events (above a certain threshold), and certain other air turbulence, for up to 6 or 7 km ahead of the aircraft.

The S-7 committee of the SAE has developed an ARP (4102/11) which addresses windshear alerting. It proposes the following definition for the alerting threshold, based upon either in-situ, or look-ahead, sensed winds:

"3.1.5 Windshear alert threshold (in the energy loss sense) should be the lesser of:

a) a windshear of 2.86 knots/s (0.15 "g") increasing tailwind component (or decreasing headwind), or

b) the equivalent energy loss rate due to vertical downdraft (0.15 x airspeed), or

c) any combination of the a) and b) such that:

$$0.15 = (1/\text{airspeed})W_v + (1/g)W_h$$

where: Wv = vertical wind speed

Wh = horizontal wind acceleration

g = gravitational acceleration

filtered for normal turbulence and maneuvering flight, or

d) upon critical degradation of performance capability (less than level flight) for existing atmospheric conditions and aircraft configuration.

When aircraft systems allow, filtering as stated above should consider any wind correction factor input."

The ARP goes on to define the following three alerting levels:

"3.2.7 <u>Windshear Warning Alert</u>:

3.2.7.1 Windshear Warning Alerts shall activate no later than exceedance of the threshold defined by 3.1.5.

3.2.7.2 Windshear Warning Alerts shall cease when adverse conditions no longer exist, Adverse conditions include, but are not limited to, the attainment of a minimumaltitude or a finite timespan (for example, 30 s), may be applicable to the cessation of alerts.

3.2.8 <u>Windshear Caution Alert</u>:

3.2.8.1 A windshear Caution Alert shall provide an alert of increasing performance shear no later than exceedance of the same threshold magnitudes as those defined by 3.1.5a) thru c) (opposite sign for increasing performance).

3.2.8.2 Windshear Caution Alerts shall continue for a finite time unless superseded by a Warning Alert, then cease if the conditions which initiated the alert no longer exist.

3.2.9 <u>Windshear Advisory Alert</u>:

3.2.9.1 A Windshear Advisory Alert shall provide an alert of detected shear ahead of the aircraft no later than detected exceedance of the same threshold magnitudes as those defined by 3.1.5a) thru c).

3.2.9.2 Windshear Advisory Alerts shall continue for a finite time unless superseded by a Warning or Caution Alert, then cease if the conditions which initiated the alert no longer exist."

You may want to use these definitions(referenced to increasing or decreasing performance wind threshold), or derivations of them, as your criteria for the alerting levels; the only requirement is to pick criteria that you feel are consistent with the set of alerting level definitions designed for this task(which are referenced to crew response requirements).

To give you some additional references, the "Crew Action Model" and "Microburst Windshear Probability Guidelines" from the FAA's Windshear Training Aid are provided as Exhibit I. These were a comparable model and self-alerting criteria ("probability guidelines") established for the pre-detection-system environment.

The following assumptions concerning the capabilities of the look-ahead sensors and the information that could be available on the flight deck should be used in your deliberations.

1. Horizontal wind velocities in excess of 15 kts (either head- or tail-wind) will be available along the flight path (between 1000 and 100 ft AGL) up to 6 kilometers (83 seconds at 140 kts) ahead of the A/C, with an accuracy of about 2-4 kts.

2. Vertical winds will probably not be available from the on-board sensors; there may be only a limited ability to estimate them from other characteristics.

3. Horizontal wind velocities at, or near, ground level might be available in the area of the airport from LLWAS systems, but because the systems exist only at certain airports, their availability cannot be relied upon.

4. Areas where a possible microburst is occuring may be identified from TDWR systems, and could be available by voice or data link transmission at certain airports but not at others.

5. Microburst/windshear/gust PIREPs may, or may not, be available.

6. All information currently available on EFIS-equiped A/C will probably be available.

Again, the above information is provided for background purposes, and not intended to encourage you to take a particular position based upon the ARP or any associated definitions or recommendations. Rather, we are attempting to get at the criteria and procedures questions from an "crew alerting and response" angle.

We greatly appreciate the time required to give this your due consideration. Please return the completed forms (make a copy if you wish) to:

Charles Anderson
Flight Deck Research
M/S 96-06

Thank you for your participation. I'll keep you informed of the progress and outcome of this development effort.

EXHIBIT I.

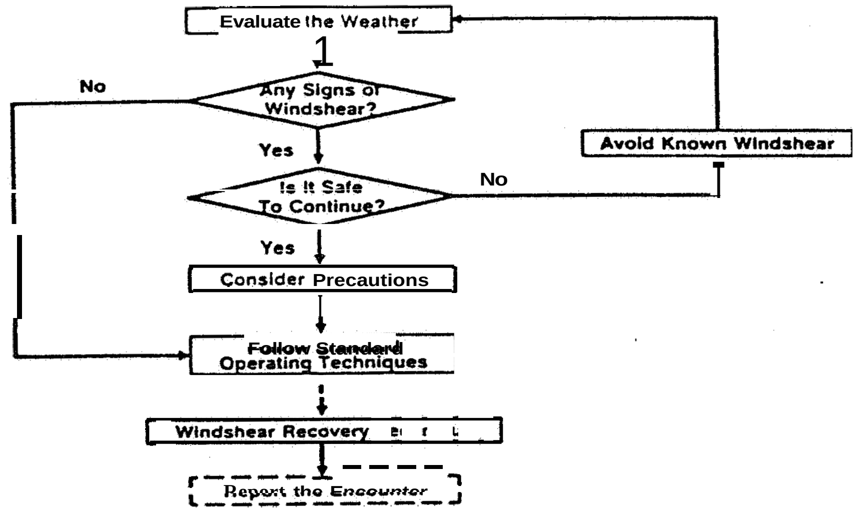


Figure 25. Model *of flight* crew actions.

TABLE 1

MICROBURST YINDSHEAR PROBABILITY GUIDELINES

OBSERVATION	PROBABILITY OF WINDSHEAR
PRESENCE OF CONVECTIVE UEATHER NEAR INTENDED FLIGHT PATH:	
- Yith localized strong wfnds (Tower reports or observed blowing dust, rings of dust, tornado-1ike features, etc.)	HIGH
- Yith heavy precipitation (Observed or radar indications of contour, red or attenuation shadow) ...	HIGH
- Yith rainshower	MEDIUM
- Yfth llghtnfng	HEDIUM
- Uith vfrga	MEDIUM
- Yith moderate or reater turbulence (reported or radar indications!	MEDIUM
- Yith temperature/dew point spread between 30 and 50 degrees fahrenheit	HEDIUM
ONBOARD YINDSHEAR DETECTION SYSTEM ALERT (Reported or observed).....	HIGH
PIREP OF AIRSPEED LOSS OR GAIN:	
- 15 knots or greater	HIGH
- Less than 15 knots	MEDIUM
LLUAS ALERT/WIND VELOCITY CHANGE	
- 20 knots or greater	HIGH
- Less than 20 knots	MEDIUM
FORECAST OF CONVECTIVE WEATHER	LOW

NOTE: These guidelines apply to operations in the **airport vicinity (within 3** miles of the point of takeoff or landing along the **intended** flight path and below **1000** feet **AGL).** The clues should be considered cumulative. **If more** than one **is** observed the **probability** weightfng should be increased. The hazard **increases** with proximity to the convective weather. Weather assessment should be made continuously.

CAUTION: CURRENTLY NO QUANTITATIVE MEANS EXISTS FOR DETERMINING THE PRESENCE OR INTENSITY OF MICROBURST YINDSHEAR. PILOTS ARE URGED TO EXERCISE CAUTION IN DETERMINING A COURSE OF ACTION.

A. Criteria Blocks

1. Criteria for Time-Critical Alert:

2. Criteria for Warning Alert:

3. Criteria for Caution Alert:

4. Criteria for Advisory Alert (a block is not shown for this, but include if item(s) is different or in addition to first decision item in flow: "Is there any sign of windshear?"

B. Procedures Blocks

5. Procedures unique to a windshear Time-Critical Alert:

6. Procedures unique to a windshear Warning Alert:

7. Procedures unique to a windshear Caution Alert:

8. Procedures unique to a windshear Advisory Alert:

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13. ABSTRACT *(Maximum 200 words)*

The goal of this research effort was to conduct analyses and research which could provide guidelines for design of the crew interface of an integrated windshear system. Addressed were HF issues, crew/system requirements, candidate display formats, alerting criteria, and crew procedures. A survey identified five flight management issues as top priority: 1) missed alert acceptability; 2) avoidance distance needed; 3) false alert acceptability; 4) nuisance rate acceptability; and 5) crew procedures. Results of a simulation study indicated that the warning time for a look-ahead alert needs to be between 11 and 36 seconds (target of 23 seconds) before the reactive system triggers in order to be effective. Pilots considered the standard go-around maneuver most appropriate for look-ahead alerts, and the escape maneuvers used did not require lateral turns. Prototype display formats were reviewed or developed for a) alerting the crew; b) providing guidance to avoid or escape windshear; and c) status displays to provide windshear situational awareness. The three alerting levels now in use were considered appropriate, with a fourth (time-critical) level as a possible addition, although many reviewers felt only two levels of alerting were needed. Another survey gathered expert opinion on what crew procedures and alerting criteria should be used for look-ahead, or integrated, windshear systems, with a wide diversity of opinion in these areas.

14. SUBJECT TERMS
Airborne windshear detection; Flight crew interface; Look-ahead windshear detection; Predictive windshear; Crew alerting; Crew procedures; Crew information requirements; Flight deck displays; Crew interface issues

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